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**LOCATE FRESH WATER AND DETERMINE SOIL
PROPERTIES USING CONDUCTIVITY
MEASUREMENTS**

Funded by: The Agriculture Development Fund

March 2011

Prepared by: Ecotech Research Ltd.

FINAL REPORT

**Locate Fresh Water and Determine Soil
Properties Using Conductivity
Measurements**

Final Report

Project Number 2008-0057

**Prepared by Evan Morris
EcoTech Research Ltd.
March 31, 2011**

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Summary

- We designed, built and successfully tested a mobile platform that records ground conductivity data simultaneously from four conductivity instruments and a GPS receiver. We carried out field trials during all seasons. We have carried out an evaluation of the various modifications we have made to how the EM38, EM31 and EM34 instruments are now used in conductivity surveys. Individuals have given positive responses to the changes we have made, and have suggested various improvements which we will attempt to incorporate into the system.
- We have determined that airborne electromagnetic methods can be used to find fresh water supplies in the buried glacial valleys which are found in Saskatchewan. We have had discussions with the SkyTEM company to determine how such a survey should be conducted in the province, and how much it would cost.
- We conducted a detailed review of the literature in order to determine if other ground based electromagnetic instruments should replace the Geonics instruments currently used by AESB and the SAF Irrigation Branch. We believe the GEM-2 is not a good alternative to the Geonics instruments. We believe the DUALEM instrument is an improvement over the Geonics instruments. We have purchased and successfully tested the DUALEM 421 instrument.
- We have redesigned our penetrometer so that it can simultaneously measure subsurface conductivity and soil moisture levels. We will construct this instrument in 2011.
- We have successfully used the EM34 mounted in its precision frame to map aquifers in Manitoba.
- We have developed a number of computer models of near-surface water sources. We have tested our models using both the EM34 and EM38 instruments. The EM34 models were extremely helpful in interpreting the Manitoba data. The drill core observations we received from the Sask. Irrigation Branch were useful in testing some of our model assumptions. We discovered that if we are making models for the EM38, we need to run lab tests on soil cores at shorter intervals than 30 cm in order to test the models properly.
- We spent a large effort on using traditional inversion methods to estimate subsurface conductivity patterns. These methods do not require the construction of models, and should be able to estimate conductivity changes with depth directly from multiple height or multiple instrument measurements. Our efforts in this regard were unsuccessful. However we have determined that a new inversion method called the genetic algorithm should be able to accurately estimate subsurface conductivity conditions. We have done a literature search, and are in contact with a local researcher who has successfully used this method in other areas of science.
- We were unable to complete the proof-of-concept study to determine if the seismoelectric method can locate fresh water sources.

RESEARCH OBJECTIVE 1

Design and construct a mobile platform to simultaneously record information from four ground conductivity instruments and a GPS receiver

EcoTech Research has worked with several ground conductivity meters in order to estimate soil properties, including the presence of water, beneath the surface. Figures 1-3 illustrate the three Geonics instruments that we have worked with (pictures courtesy of Geonics Limited).



Figure 1: EM38-DD

This instrument combines two electromagnetic sensors. One measures soil conductivity values to a depth of approximately 0.75 meters, while the other measures values to a depth of approximately 1.5 meters.

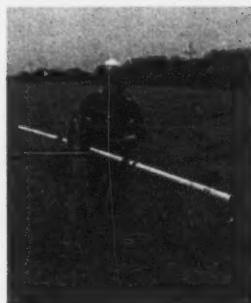


Figure 2: EM31

This instrument measure soil conductivity values to a depth of approximately 6 meters.



Figure 3: EM34

This instrument measures soil conductivity values to a depth of approximately 15 meters.

The various depths of penetration of each instrument allows us to select a specific instrument if we know at what depth a water source is likely to be found. If we don't know the depth, we can carry out a multi-instrument survey, which will provide us with information at various depths. The instruments are attached to an ATV with a precision

frame, which reduces errors due to the misalignment of instruments and interference between the various instruments.

In 2007 we successfully attached the EM38-DD ground conductivity meter to an ATV, and towed the EM31 behind the ATV (Figure 4). This allowed us to speed up survey times and collect information on soil properties at different depths.

Figure 4 – EM38-DD and EM31 attached to an ATV



During this project we worked on adding the EM34 instrument to the ATV and attaching the EM31 directly to the ATV. The EM34 provides measurements of soil properties at greater depths than the EM38 and EM31 instruments, and will allow us to find aquifers that might be missed by the other two instruments.

We had to overcome several problems in order to add the EM34 to the ATV:

- We had to attach the EM34 to the ATV in such a way that interference due to the metal in the ATV was negligible.
- We had to attach the EM34 and the EM31 to the ATV so that the two instruments would not interfere with each other.
- We had to design and construct a precision frame to hold the EM34 transmitter and receiver coils in a plane. The EM34 instrument provides accurate readings only if the transmitter and receiver coils are coplanar. Measurement error is considerable if the transmitter and receiver coils are even a few degrees out of alignment. We had to construct the precision frame so that:
 - The transmitter and receiver coils remain coplanar to within acceptable tolerances.
 - The frame will not break when the ATV travels over rough ground.
 - The material in the frame will not interfere with the EM34 measurements.

We had to deal with similar problems in order to attach the EM31 to the ATV:

- We had to attach the EM31 to the ATV in such a way that interference due to the metal in the ATV could be filtered out of the data.
- We had to design and construct a frame to attach the EM31 to the ATV.

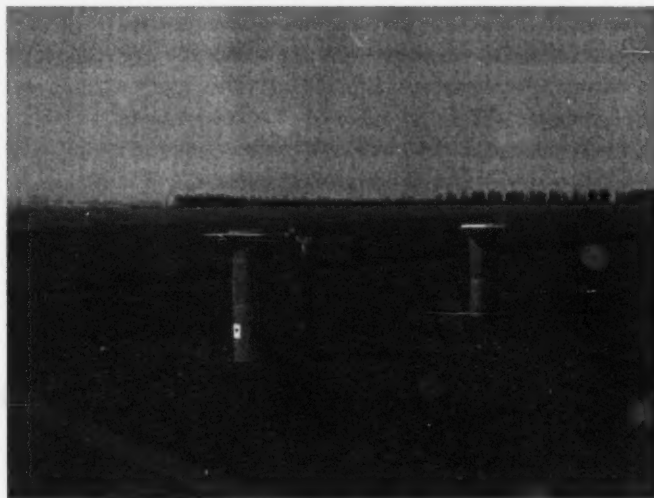
Objective 1A Determine how the metal in the ATV transporting the instruments interferes with each instrument

We wanted to ensure that the metal in the ATV would not create large errors in the conductivity readings made by the EM34. In 2007 we carried out tests to determine the size of the measurement error as the EM38 instrument was placed at different distances from the ATV. We used the same methodology in 2009 to determine the effect of the metal in the ATV on the EM-34 and EM31 instruments.

Tests conducted to determine the effect of metal in the ATV on the EM34 follow:

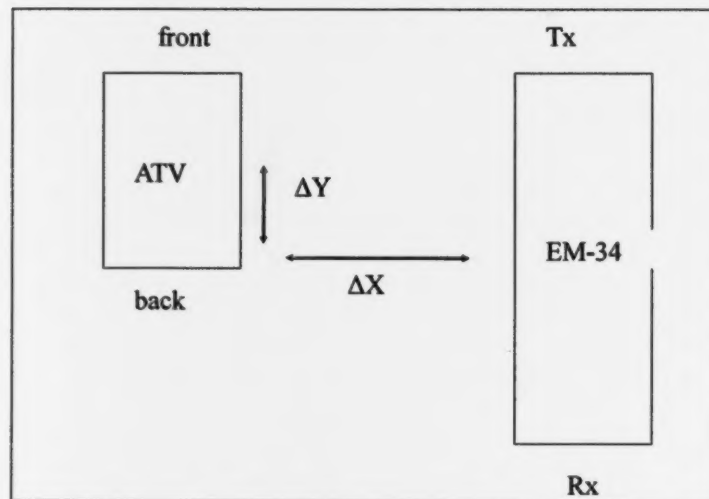
Step 1: We measured ground conductivity with the EM34 when no metal objects, including the ATV, were nearby. We took readings at several instrument heights, since we had to attach the EM34 to the ATV at above ground level (Figure 5). The transmitter and receiver coils are 10 meters apart, and will be positioned in front of and behind the ATV. If the coils are too low to the ground, they will hit the ground in rough terrain.

Figure 5 Measuring EM34 readings when no metal is nearby



Step 2: Once the previous readings were made, we brought the ATV increasingly closer to the EM34 and took measurements at each distance (Figures 6 and 7).

Figure 6 Moving the EM34 closer to the ATV



We took the last measurement with the ATV directly beneath the EM34 instrument. We then calculated the magnitude of the interference errors as a function of the distance between the EM34 and the ATV.

Figure 7 Moving the ATV close to the EM34



Step 3: We then took measurements by placing the ATV directly between the EM34 coils, and then moving the ATV forward and backward (Figure 8). This allowed us to determine how the measurement error changed when the ATV was placed closer to either the transmitter coil or the receiver coil.

Figure 8 The ATV between the EM34 coils



We conducted a similar series of tests to determine the effect of the ATV on the EM31 instrument.

Results

We determined how far from the ATV we must place the instruments in order to reduce the interference from the ATV. We also determined that the remaining interference is constant, and that we can subtract the interference effect from each measured value.

Test results are documented in Appendix 1A.

Objective 1B Determine how the conductivity meters interfere with one another

In 2007 we determined how to orient the EM38DD and EM31 instruments to one another in order to reduce interference effects to low levels. For this project we had to determine how the EM31 and EM34 would interfere with each other and how the EM38DD and EM34 would interfere with each other. We conducted separate interference tests with the EM31 - EM34 instrument pair and the EM38DD - EM34 instrument pair. For each pair of instruments we varied the horizontal distance, vertical distance, horizontal offset and instrument orientation and determined how each of these factors affected the accuracy of the measurements. We conducted the tests as follows:

- We placed one instrument on the ground and measured conductivity when the second instrument was far away.
- To determine the effect of the second instrument on the first instrument, we placed the second instrument parallel to the first instrument. We placed the transmitter and receivers of the two instruments in the same orientation. We recorded conductivity measurements from the first instrument as we brought the second instrument closer to it (Figures 9 and 10).

Figure 9 Testing for interference between the instruments

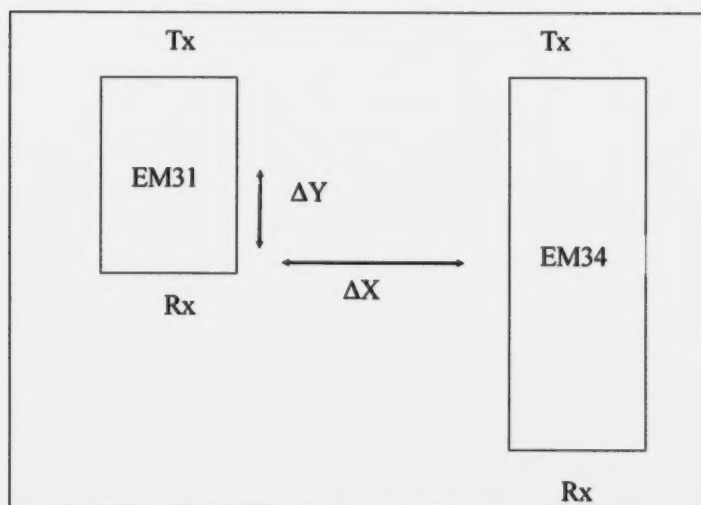
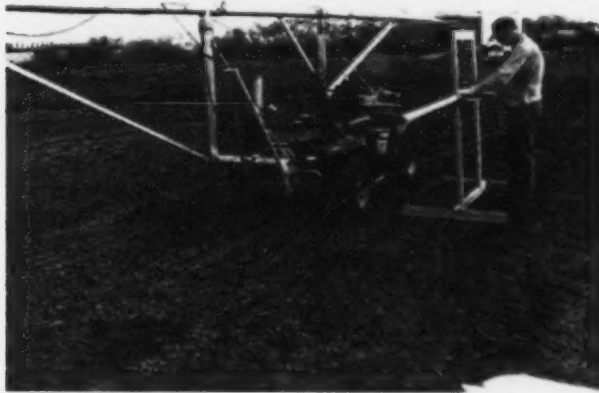


Figure 10 Measuring how the EM31 interferes with the EM34



- We then offset the second instrument horizontally from the first instrument, and measured again.
- We repeated the above tests with the transmitter and receiver of the second instrument in an orientation opposite to that of the first instrument.
- We repeated the above three steps while holding the second instrument stationary and bringing the first instrument closer to it.

Results

A high level of interference occurs if the transmitter of one instrument is very close to the receiver of a second instrument. We discovered that attaching the instruments to the ATV so that the instrument transmitters are far away from any receivers reduces the interference to low levels.

Test results are documented in Appendix 1B.

Objective 1C Design the mobile platform

The design of the mobile platform to carry the three electromagnetic instruments was subject to the following constraints:

- The instruments had to be mounted far enough away from the ATV so that the interference from the metal in the ATV would be small.
- The instruments had to be mounted in such a way that the mutual interference between them would be small.
- The EM31 and EM34 instruments would have to be mounted so that the transmitter and receiver coils would remain aligned in the same geometric plane as the ATV moves.
- The frame holding the instruments must be robust and not break down due to vibrations during soil surveys over rough terrain.

The first two constraints were easily met based on the research results we had acquired in carrying out Objective 1B. The third and fourth constraints were determined as described below.

Alignment of the EM31 and EM34 transmitters and receivers

The frame attaching the EM31 and EM34 instruments to the ATV consists of booms (pipes) to hold the instruments away from the ATV and from each other in order to reduce interference effects. The transmitters and receivers of EM31 and EM38 instruments are enclosed in solid cases. The EM38 case is extremely rigid, and the transmitter and receiver coils remain in the same geometric plane as the instrument is moved (Figure 1). The EM31, which is longer, is also enclosed in a plastic shell. When carrying the instrument by hand, as shown in Figure 2, the tubular shell flexes, which may cause slight misalignment of the transmitter and receiver, located at opposite ends of the instrument. In the past we have placed the EM31 in a rigid carrier to prevent misalignment of the transmitter and receiver coils.

The EM34 consists of two coils, each of which is approximately 1 meter in diameter (Figure 3). The coils have to be placed 10 meters apart. The manufacturing company does not provide a casing to hold the EM34 transmitter and receiver coils in alignment.

Prior to designing the platform to hold the EM34, we needed to determine how rigid to make the frame. The required degree of rigidity would depend on the size of the measurement error that would occur if the transmitter and receiver coils were misaligned.

We conducted an exhaustive series of tests to determine how different forms of coil misalignment would affect the accuracy of EM34 measurements. We first took a measurement when the two coils were properly aligned. We then changed the alignment of the transmitter coil and recorded the measurement error. We changed the alignment of the transmitter coil by tilting one end of the coil and measuring the angle that the transmitter coil made with the receiver coil. We recorded a number of readings at different angles. We also changed the misalignment geometry by tilting different ends of the receiver coil. In

addition, we lifted the entire coil, so that the two coils remained parallel with one another, but were now in separate planes. We conducted a similar set of experiments where the transmitter coil remained fixed while the orientation of the receiver coil changed. We also conducted a set of experiments where we moved both coils simultaneously.

Results

Coil misalignment causes serious errors. The magnitude of the error depends on two factors: how the coils are misaligned with one another, and the number of degrees they are misaligned. Misalignments of 5 degrees or more can result in errors of 30% or more, depending on how the two coils are misaligned. Misalignments of 2 degrees can result in errors of 7% or more, depending on the direction of misalignment.

We determined that our design should keep the coil misalignment under 2 degrees. To address this problem we designed a precision frame that keeps the coils aligned as the mobile platform travels over rough ground. The frame was fabricated by Ground Effects Ltd in Regina.

Test results are documented in Appendix 1C.

Rigidity and ruggedness of the instrument platform

Our original platform design avoided the use of all metal objects, as metal has high conductivity. A metal platform might give erroneously high conductivity readings.

We based the first designs on using PVC or carbon fibre pipes to attach the conductivity meters to an ATV. We eliminated this design when we realized that driving an ATV over fields creates vibrations in the platform that will result in catastrophic failure of the PVC or carbon fibre pipes. PVC and carbon fibre pipes are also prone to crack when conducting surveys in subzero temperatures.

The remaining options were to construct the platform of metal or wood. To determine to what extent a metal frame would create errors in the conductivity readings, we conducted a number of experiments with the EM31 and EM34 ground conductivity meters. We placed steel and aluminum bars at different locations and orientations to the instruments and determined the size of the error due to the presence of the metal (Figure 11).

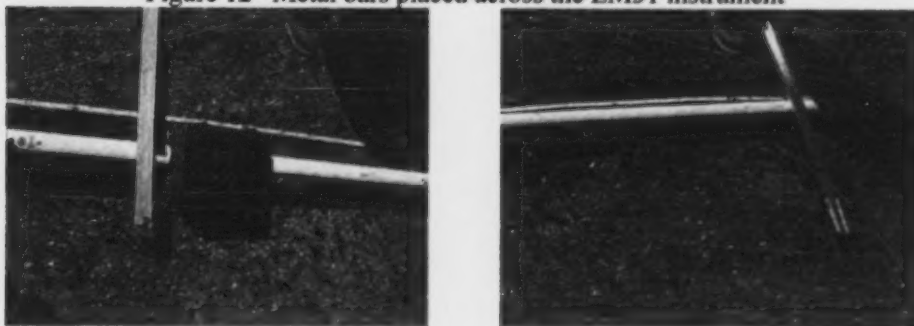
Figure 11 Aluminum pipes attached to the EM34 coil



The EM31 is 3.66 meters long. The transmitter and receivers are located at each end of the instrument, and the control and recording hardware is located at the centre of the instrument. A platform constructed to hold the EM31 away from the side of the ATV requires metal bars be placed parallel to the ATV, to support the EM31 at various points. Such a platform also requires metal bars be placed perpendicular to the EM31, to attach this frame to the ATV.

We conducted a series of tests to determine the effect of metal bars on the accuracy of the apparent conductivity measurements. We measured the effective conductivity of the EM31 with no metal nearby, and then with aluminum and steel bars. First we placed aluminum bars perpendicular to the EM31 at various locations along the instrument and repeated the measurements using steel bars (Figure 12).

Figure 12 Metal bars placed across the EM31 instrument



We conducted similar tests placing aluminum and steel bars parallel to the EM-31 instrument (Figure 13).

Figure 13 Metal bars placed alongside the EM31 instrument



We also carried out tests with the EM31 to determine the level of error with the distance of the EM31 from the ATV and frame. We also determined the level of error from the ATV when the EM31 was placed at different heights above the ground.

Results

Our tests showed that we could use either aluminum or steel rods to hold the electromagnetic instruments and hold them onto the ATV. We discovered that the shorter EM38 instrument was most susceptible to interference from nearby metal, and that the 10 meter long EM34 was least susceptible. We could place metal rods very near to the EM34 coils without any noticeable error. We were even able to place metal bars on the EM34 coils with only minor measurement errors. These errors are systematic and can easily be removed from the data.

As a result of these tests we decided to construct the frame out of aluminum, which is lighter than steel. Using aluminum will make it easier to drive the ATV.

Test results are documented in Appendix 1D.

Objective 1D Construct the mobile platform

Two precision frames were constructed by Ground Effects Ltd in Regina. One frame was built to attach the EM34 instrument to the ATV. The second frame was built to attach the EM31 to the ATV.

The EM34 provides measurements of soil properties at greater depths than the EM38 and EM31 instruments, and will allow us to find aquifers that might be missed by the other two instruments. We constructed and tested the multi-instrument platforms, which are shown in the following pictures.

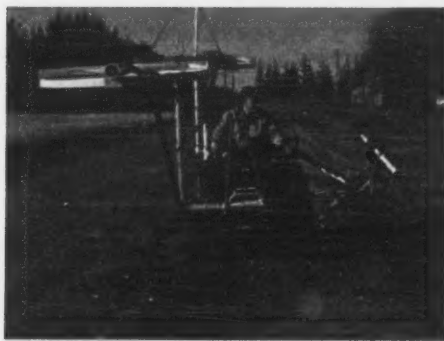


Figure 14
A front view of the EM31 and EM34 attached to the ATV.

Figure 15
Side view of the ATV and the three electromagnetic instruments. The EM38 is towed behind the ATV.

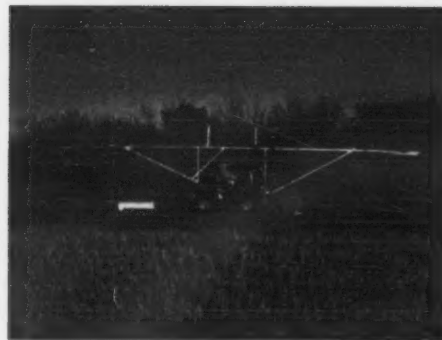


Figure 16
The high clearance of the instruments allows the ATV operator to conduct surveys on fields where the ground is sloped.

Objective 1E Create a computer program to simultaneously read data from four conductivity meters and a GPS unit

We modified the software that we had created in 2007 under Project # 20060131. The current software can read data from all five instruments, and contour the data from the four conductivity meters.

Objective 1F Field test the computer program

We have successfully field tested the software at a number of sites.

Objective 1G Field test the mobile platform and refine the design

Our first design kept the coils aligned so that there was minimal measurement error when a survey started. However, the coils became progressively misaligned after we drove the ATV for a while. We adjusted the design slightly to address this problem. Once Ground Effects incorporated this change, the frame kept the coils properly aligned as the survey progressed.

We continued our field tests of the precision frame, and as a result we made a third, minor change that improved the rigidity of the frame.

In March and April of 2010 we conducted an evaluation of the mobile platforms we had designed for the EM38, EM31 and EM34 ground conductivity meters. During 2009 we had gained extensive experience using these instruments under different conditions. In early 2010 we evaluated the effectiveness of these mobile platforms compared to the survey methods they replaced.

The evaluation involved carrying out discussions with the following individuals:

- EcoTech personnel who had worked on developing the system
- Staff at Ground Effects Environmental Services in Regina who had been involved in the fabrication of the EM31 and EM34 mobile platforms
- Personnel at the Irrigation Branch in Outlook who have developed a mobile platform for the EM38 system
- AESB personnel in Regina who have been involved in designing and testing the mobile carriers for the EM38, EM31 and EM34 systems
- AESB personnel in Manitoba who have used sled based EM38 systems as well as mobile EM31 and EM34 systems.

Evaluation methodology

Over the past year our company has kept a record of the various comments and suggestions that individuals have made regarding the mobile platforms. Many of these suggestions have already

been acted upon. In March of this year we created a list of the advantages and disadvantages that people had come up with for each of the instrument platforms. We then asked people whether they agreed or disagreed with these comments based on their own experiences, and to list any other advantages or disadvantages that were involved in switching to the new precision carriers. We also asked them to provide us with other suggestions for the improvement of the precision carriers.

During February and March of 2010, AESB held two week-long training courses at AESB's Maxwell Laboratory in Regina. During these sessions the staff at Maxwell demonstrated the EM38, EM31 and EM34 instruments in their precision frames attached to an ATV. Participants from Outlook and from Manitoba who had experience using these electromagnetic instruments examined the instrument platforms and provided us with useful feedback.

We also spoke with individuals informally on a one-to-one basis in order to clarify problems that people had encountered or to get more details about their suggestions.

EM38 – Comparing the effectiveness of placing the EM38 on a boom compared to towing the EM38 on a sled

AESB's EM38 towed by the ATV

Figure 17



Figure 18

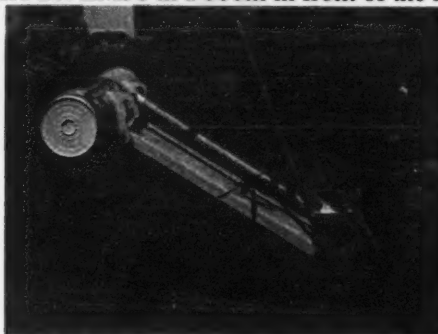


The EM38 is placed in a protective plastic box which is then placed on a child's snow sled. The sled is cheap and robust. The box protects the instrument if the sled tips over or if the sled runs into an obstacle on the ground.

Figure 19: A PVC pipe based sled used by the Irrigation Branch



Figure 20: EM38 in a boom in front of the ATV



The above figure shows how the EM38 is attached to the front of the ATV. The boom can be raised or lowered by the driver.

Advantages of using a front boom compared to pulling a sled

1. Measurement error can be reduced when the operator can select an instrument height that is appropriate to field conditions.
 - Fewer measurement errors occur when the EM38 is in a boom since the height of the instrument will be fairly constant over the course of a field survey. If the instrument is in a sled, the height of the sled above the ground will change as the sled is pulled over stubble, ruts, bush, tumbleweed, etc. Increasing the height of the sled will result in lower conductivity readings, even if the soil conductivity does not change. As a result conductivity lows may be misinterpreted as being due to changes in soil properties, when they are actually due to the bouncing of the sled over the ground.
 - In order for the EM38 instrument to provide accurate readings, the instrument must remain in a vertical orientation. A shift in instrument orientation will result in a conductivity measurement error. The orientation of the EM38 in a boom is more likely to remain vertical when the ATV drives over ruts from combines and irrigation systems, or when there is high stubble.
 - A sled mounted system is more likely to collect chaff and loose soil on the sled. The conductivity of this material may affect the instrument readings.
2. A second advantage of a boom mounted system is that at a single location multiple readings can be made at different elevations. This provides information on conductivity changes with depth.

Disadvantages of using a front boom compared to pulling a sled

1. The setup time is ten minutes longer when the 38 is placed in a boom rather than in a sled.
2. Conductivity readings are lower when the EM38 is above ground level in the boom.
 - In most cases changes in subsurface conductivity will still be detected over a field, even if the measured readings are lower (Morris, 2009).
 - For some applications height correction formulas will need to be applied to the readings made by the instrument in the boom.
 - Formulas that estimate salinity levels from ground-based EM38 measurements will need to be rederived in order to estimate salinity levels from above ground readings.
 - Geonics states that measurement errors for the EM38 are typically around 1 mS/m. If an apparent conductivity measurement at ground level is 50 mS/m, then this should be interpreted as 50 ± 1 mS/m. In this case the error level is 2%. If the instrument is placed in a boom, the reading at the same location may be 25 mS/m. The measurement error will still be 1 mS/m. In this case the error level is now 4%. In other words, raising the instrument increases the relative measurement error of the instrument.

Other observations

The ATV speed at which a survey can be carried out using a sled or a front boom are similar.

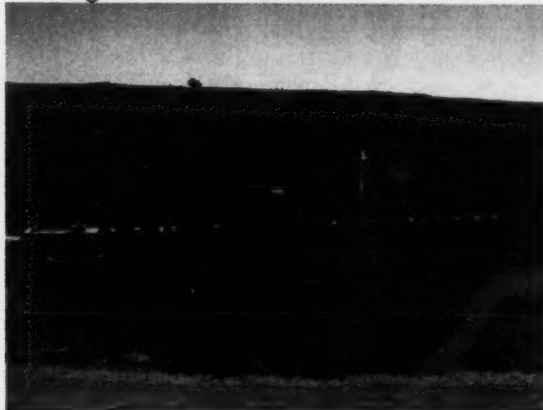
Suggestions

It would be better to place the boom behind the ATV rather than in front. Then it is less likely to get caught in things, and the body of the ATV will protect the EM38 from obstructions such as bushes, fences, etc.

Comparing the effectiveness of placing the EM31 on a side boom versus towing the EM31 behind the ATV

The EM31 instrument has a greater penetration depth than the EM38. It achieves this greater penetration by having a greater separation between the transmitter and receiver coils. In the EM38 the coils are 1 meter apart. The intercoil separation is 3.66 meters for the EM31. This greater instrument length makes it difficult to tow the instrument on a sled. Most surveyors place the EM31 in a wheeled platform and tow it behind an ATV.

Figure 21: Cart used to hold the EM31



The above picture shows the box that is constructed of wood and fiberglass that is used to carry AESB's EM31 instrument.

Figure 22: EM31 cart towed by the ATV



A long fibreglass/wood box is used to connect the ATV to AESB's EM31 instrument box. This was done to keep the EM31 away from the ATV so that there would be negligible interference from the metal in the ATV.

The following pictures show how the EM31 is side-mounted onto the ATV through the use of the precision frame we designed. Our tests show that the aluminum frame has a negligible effect on the instrument measurements. The side mount is placed 1 metre away from the ATV. At this distance the level of interference from the metal in the ATV is minor.

Figure 23: Attaching the precision frame to the ATV

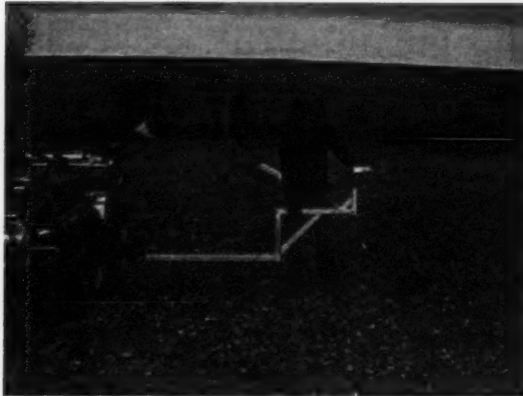


Figure 24: The attached frame

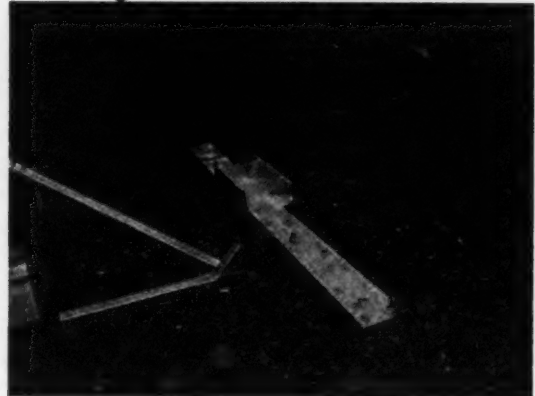


Figure 25: The EM31 attached to the precision



Figure 26

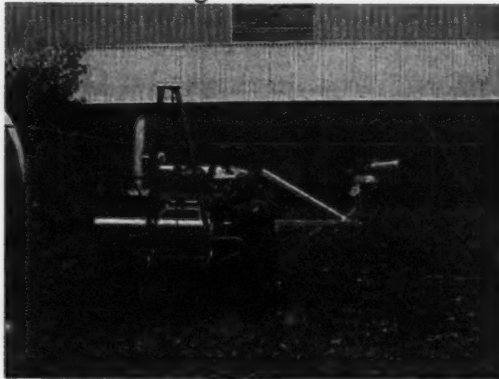
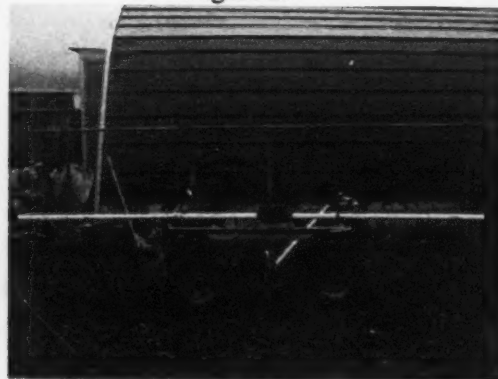


Figure 27



Front and side views of the EM31 mounted on the side of the ATV

Advantages of using a side boom instead of towing the EM31

1. Setup and take down time is shorter for the side mounted EM31.
2. Less material needs to be transported for the side mounted system.
3. The turning radius is smaller.
4. In cases of rough terrain or where shallow pits occur, the wheels of the towed system sometimes hang, and sometimes the towed mount pulls off the hitch. This is not a problem for the side-mounted system.
5. If the EM31 is placed at a height of 1 metre, no height corrections are necessary, as Geonics has already incorporated 1 metre height corrections into the instrument. Height corrections are necessary if the instrument is close to the ground, as for the towed system.

Disadvantages of using a side boom

1. There is more chance that the side mounted EM31 will be involved in collisions with trees and fence posts than a towed system would.
2. There is more chance of damage to the side mounted system than the towed system. The side mounted EM31 is unprotected, while the towed version is protected by a box made of wood and fibreglass.
3. Field repairs to the precision frame are more difficult, as repairs require welding.

Suggestions

1. Build a protective cover at the front of the side mounted EM31.
2. Build a protective cover for the EM31 control panel, which is located at the centre of the EM31.
3. The attachment mechanism can be improved for easier setup onto the ATV.

Comparing the effectiveness of placing the EM34 on a precision frame versus the previous system

The previous system

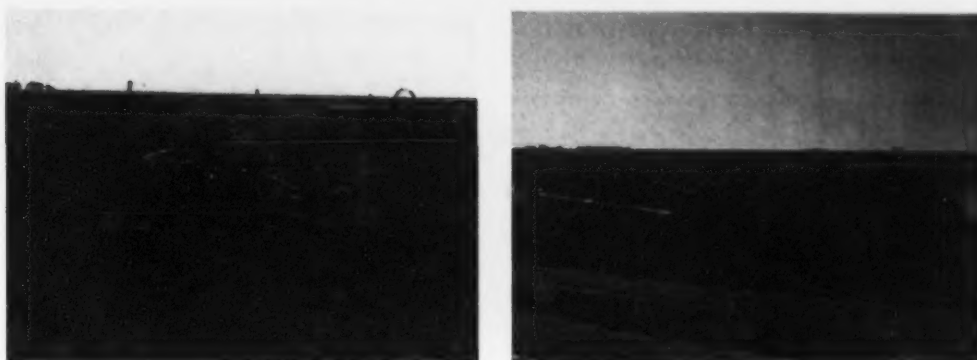


Figure 28 The previous system used by AESB personnel in Saskatchewan involves placing the EM34 transmitter and receiver coils at the ends of two fibreglass booms that are attached to an ATV. The coils have to be exactly 10 meters apart. The booms are elevated by a winch.

Figure 29 The picture on the right displays the equipment that must be attached to the ATV during the setup process



Figure 30 The picture on the left shows the EM34 setup used by AESB personnel in Manitoba. As can be seen in the two pictures on the left, the EM34 transmitter coils of both the Saskatchewan and Manitoba systems are not parallel to each other. This causes substantial measurement errors. If the coils are out of alignment by 10%, the measurement error can be as high as 70%.



Figures 31 and 32: The EM34 used for a soil survey.

The EM34 attached to the precision frame

In 2009 a precision frame was designed and constructed for the EM34. The EM34 instrument was placed on a rigid aluminum frame. The most important feature of this frame is that it keeps the transmitter and receiver coils in the same plane.

Figure 33: The EM34 mounted in the precision frame



Setup of the EM34 precision frame system

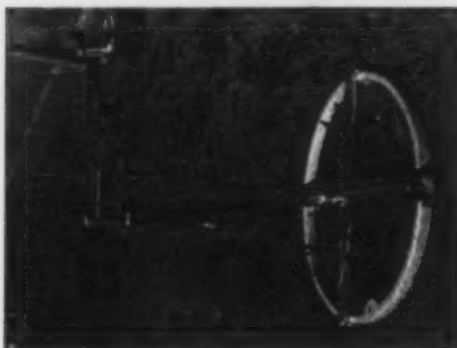


Figure 34: The various parts are laid out on the ground.

Figure 35: The frame is assembled



Figure 36: The frame is lifted onto the ATV

Figure 37: The transmitter and receiver coils are attached to the precision frame



Advantages of using the precision frame for the EM34

1. Conductivity readings are far more accurate, as the aluminum frame keeps the coils coplanar. The coils are considerably out of plane in the fiberglass carrier. Even small changes, such as a 5 degree difference in the orientation of the transmitter and receiver coils, can create large measurement errors.
2. The turning radius can be smaller if fences are not too high.
3. With the new system, the aluminum frame is a bit higher than the wood/fiberglass booms. Therefore the new system can clear some obstacles that the fiberglass system cannot. It is easier to avoid ground-based obstacles such as large rocks or low shrubs.
4. The increased height of the sensors reduces the magnitude of the EM readings, which reduces non-linearity problems when interpreting the data.
5. The EM34 precision frame provides more visibility for the ATV operator than the fiberglass/wood frame. This fiberglass/wood frame obscures the presence of rocks and dips in the ground in front of the ATV.
6. It is easier to switch from the vertical dipole to the horizontal dipole orientation if two surveys are to be made over the same area.
7. While setup time for the 34 aluminum frame is about the same as for the fiberglass system, the aluminum system is easier to setup.
8. The winches slip on the 34 fiberglass system.

Disadvantages of using the precision frame for the EM34

1. The height of the frame increases the centre of gravity of the ATV and makes it more likely to tip over.
2. Collisions with trees are more of a problem.
3. There is a learning curve for setup and takedown of the aluminum frame and EM34.
4. Field repairs to the precision frame are more difficult, as repairs require welding.

Similarities between the precision frame and the wood/fiberglass frames

1. Setup and takedown time are similar once the setup method has been learned.
2. Two people are required to set up and take down
3. Turning radius is about the same in most circumstances.
4. Survey speed is similar.
5. Ditches and topography create similar types of problems for both systems.

Suggestions

1. The frame design could be improved to make setup/takedown easier.
2. A hydraulic system could be used to attach the precision frame to the ATV. Once the ATV is removed from the trailer, the operator can press a button and the precision frame would open out from the ATV. This process is used on several different types of farm equipment. A hydraulic system would result in a much faster setup time. Also the frame would be more stable.
3. Replace the ATV with a more robust vehicle. The following picture demonstrates the vehicle that the Irrigation branch is using to pull their EM38 system.

Figure 38: Vehicle used by the Irrigation Branch



This type of vehicle has a wider wheel base, is lower to the ground, and has a lower centre of gravity. It is less likely to roll over in rough terrain. It also has more power than the ATV currently in use. The enclosed cab also provides protection for the driver and the on-board computer from the weather. The cab also provides driver protection in case of a rollover.

Conclusions

The EM38 in a sled is a useful system for measuring variations in areal conductivity. The boom mounted system allows the operator to take measurements at several heights at a single location. This provides information on how conductivity changes with depth. There may also be fewer measurement errors with a boom-based system.

The EM31 system can be quickly attached and removed from the ATV. Height corrections to the measurements are not required if the EM31 is mounted at a height of 1 metre. The precision frame system can operate better in areas of rough terrain. A protective bumper needs to be designed and built in order to protect the EM31 in case of collisions with trees or fence posts.

Conductivity measurements are far more accurate when the EM34 is placed in a precision frame that keeps the transmitter and receiver coils in the same plane. Depending on the terrain, the EM34 mounted in the precision frame can be easier to manoeuvre. An enclosed tractor cab, such as that used by the Saskatchewan Irrigation Branch would increase the safety of the operator by reducing the chance of a rollover. An enclosed cab would also make it possible for the operator to conduct surveys at lower temperatures.

RESEARCH OBJECTIVE 2

Design and construct a penetrometer to measure conductivity with depth

A penetrometer is a metal tube that is pushed or hammered into the ground. Scientific instruments can be placed at the end of this tube, and measurements of soil properties can be made at different depths.

Figure 39: A commercial penetrometer

The four metal buttons are the electrodes of a conductivity measuring system.

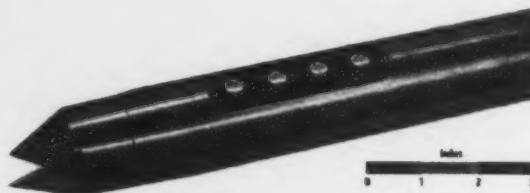
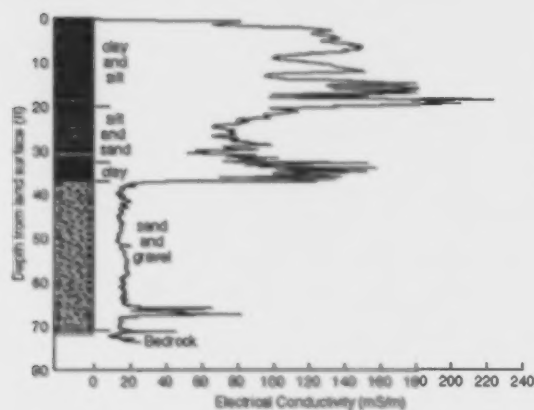


Figure 40: Conductivity readings with depth



This is an example of a conductivity survey carried out by another company. In this case the clay is more conductive than the air-filled sand and gravel layer. If water was present in this layer, the conductivity readings would be much higher.

Objective 2A Design the penetrometer

In 2009 we created designs for two penetrometers. One design is for a shallow penetration instrument and the other is a deep penetration penetrometer that requires a hydraulic hammer mounted on a truck. We designed the metal chassis of the penetrometers so that they are strong enough to use under typical field conditions. We designed the electronics using rugged electronic components. We also worked out how to record depth and conductivity as the penetrometer is forced into the soil.

In 2010 we made changes to the design of our hand-operated penetrometer. Alex Clarke is an industrial engineering student who worked for us during the summer of 2009. As part of a student project Alex and two class mates designed a spring loaded ice chipper that requires little effort on the part of the user. The ice chipper works on the same principle as an automatic centre punch. We rehired Alex in May of 2010. Alex investigated the possibility of modifying the ice chipper design so that it can be applied to a hand held penetrometer.

Our original design involved building an instrument that would measure conductivity with depth, and employed a modified Wenner design. This design has been used for many decades in the geophysical industry in the search for metal ores. The Wenner design involves 4 equally spaced electrodes placed near the end of the probe (see Figure 39).

During the summer of 2010 we explored the possibility of measuring soil moisture levels without having to take core samples to the lab. A number of hand held probes currently exist to measure soil moisture. Almost all of them have a limited depth penetration. Many of these probes require trenching or drilling in order to sample soil moisture at depths of more than 30-40 centimetres.

In November we designed the electronics for a soil moisture penetrometer that could penetrate to a depth of 1.4 meters.

In January and February of 2011 we completely redesigned the electronics for the penetrometer. We determined that we could combine the functions of measuring conductivity and soil moisture into one instrument. We did this as follows:

- We used a 4-electrode system similar to the Wenner design.
- We included circuitry that would measure the apparent conductivity of the soil averaged over a 5 cm soil thickness.
- We added circuitry that would use three of the electrodes to estimate soil moisture levels over a 4 cm soil thickness.
- The power supply would consist of a variable frequency AC current. The frequency can be set to one of two values. One frequency reduces conductivity measurement errors, while the other frequency reduces soil moisture measurement errors.
- We included an automatic switching device in the circuitry so that many conductivity and soil moisture readings are taken each second.
- The circuitry also measures the depth of the probe from the surface.

There are several reasons for building such a penetrometer:

- Ground conductivity measurements made with electromagnetic instruments need to be calibrated to the conductivity from core samples. Drilling cores is time consuming, and laboratory testing of core samples is expensive. It is much quicker to push a penetrometer into the ground than to take core samples.
- The search for new sources of groundwater involves finding locations where conductive aquifers beneath less conductive surface soils. In this case the conductivity of the earth is approximated by a two layer model – low conductivity over a higher conductivity layer. Such a model incorporates three unknown variables: the conductivity of the top layer, the conductivity of the aquifer, and the thickness of the top layer down to the aquifer. We can quickly measure the conductivity of the top layer with a penetrometer. We can estimate the conductivity of a water filled aquifer. This will allow us to estimate the depth to which we need to drill in order to reach the aquifer.
- The same two layer model can be used when conducting electromagnetic surveys in order to determine if saline water is present near the surface. We can measure the conductivity of the near surface with a penetrometer.
- The incorporation of a soil moisture meter into the penetrometer will allow producers and field agents to quickly determine what moisture levels are in the root zone.

Objective 2B Construct the penetrometer

We have not built this newly designed penetrometer yet. We will construct and test it this summer.

Objective 2C Create a computer program to record penetrometer data

We have written the software to record conductivity measurements with depth. We still need to write the software to record soil moisture levels with depth.

Objective 2D Field test the penetrometer

This objective has not been completed.

RESEARCH OBJECTIVE 3

Develop interpretation methods to analyze four instrument conductivity data and penetrometer data

Model construction

In 2009 we developed a number of subsurface soil models that we could use to try and explain conductivity measurements taken at one point. These multiple readings could either be collected by one instrument at different heights above the ground, or the readings could be due to 2, 3 or 4 instruments that take readings at the same location. Modelling allows us to easily and quickly change the assumptions regarding subsurface conditions, and determine which set of conditions best matches the various measurements that have been taken. This well known interpretation technique is called *forward modelling*.

Modelling allows us to specify how many different conductivity layers exist below the surface that are within the range of our instruments. We can also specify the thickness and conductivity of each layer. Our model will then calculate the expected conductivity reading for any instrument at any height above the ground. We then modify the input parameters in order to see what subsurface conductivity model best fits the measured values.

Some of the models we have created are displayed in Appendix 2A. We only show the models here for reference. We do not have the space to discuss them in detail.

We developed an Excel spreadsheet called *3-layer EM34 sigma_app generator.xls*. This file is a simple example of the type of modelling work we have done. It should be noted that almost all of our modelling is done using the Maple mathematical programming language. This Excel spreadsheet demonstrates how a three-layered earth can be modelled and shows how measured conductivity values vary depending on what assumptions are made about layer thicknesses and layer conductivities. This model was constructed to help us interpret the EM34 readings that were made using the precision frame. The model assumes that the transmitter and receiver coils are at the height of the boom of the precision frame. If the coils are placed at different heights, the model would have to be adjusted accordingly.

Testing models with field data

SAF's Irrigation Branch in Outlook has provided us with a large set of data. During the fall of 2009 staff at the Irrigation Branch conducted a number of field trials in various parts of the province. This work included taking cores at several locations in each field. These cores were later analyzed in the lab, and a number of physical properties were measured, including soil texture, the concentration of various ions, % saturation, conductivity and pH. Each soil core was 1.2 metres long, and lab measurements were made for each 30 cm section of core.

We also tested our models with electromagnetic and soil core data collected by the Irrigation Branch since 2002.

In addition, Irrigation Branch personnel made 14 conductivity measurements using the Geonics EM38-DD at the locations where each hole was drilled. Measurements were made at ground level and at height increments of 25 cm. Seven measurements were made with the EM38 in the vertical dipole orientation and 7 in the horizontal dipole orientation. A plastic, non-conducting ladder had been built in 2009 at AESB's Maxwell laboratory and sent to the Irrigation Branch. Irrigation branch staff would place the EM38 at different heights on the ladder and record measurements manually. This was a time-consuming task for staff members. A picture of the ladder is shown below.

Figure 41: Ladder used by Irrigation Branch Staff to take readings at multiple heights



Appendices 3A, 3B and 3C contain the field data that we collected, and that was provided to us by the Irrigation Branch and by the Indian Head Research Farm.

The table on the next two pages provides an example of how we tested our models against real data. This worksheet contains laboratory results from the core samples and the EM38 electromagnetic measurements taken at different heights. The worksheet compares our model predictions with known subsurface conductivity values. An explanation of the results is provided on the page following the table.

Comparing Ratios to Outlook Data

This worksheet uses the functions developed from the Maple sheet "EM38 2-layer ratios" to see how well they predict the Outlook core data.

For this first set, we specifically chose holes that are reasonably close to two-layer earths, using the lab results to generate the modeled ratio (Vertical to Horizontal)

Height (m)	NE12-23-07- W3M Riverhurst Hole 5		NW24-23-07- W3M Riverhurst Hole 1		NW24-23-07- W3M Riverhurst Hole 3		NW24-23-07- W3M Riverhurst Hole 2		NW24-23-07- W3M Riverhurst Hole 2		S1/2 24-10-26- W3M Maple Creek Hole 2		S1/2 24-10-26- W3M Maple Creek Hole 3	
	Well-defined two-layer earth		Poorly defined two-layer earth		Poorly defined two-layer earth		Modeled as homogenous		Modeled as two-layer		Extreme two-layer case		Extreme two-layer case	
	Observed	Model ed	Observed	Model ed	Observed	Model ed	Observed	Model ed	Observed	Model ed	Observed	Model ed	Observed	Model ed
0.00	1.59	1.44	1.40	0.81	1.39	0.76	2.60	1.00	2.60	0.95	1.24	1.05	1.36	1.68
0.25	1.71	1.71	1.67	1.33	1.80	1.29	10.00	1.45	10.00	1.41	1.42	1.48	1.54	1.82
0.50	1.90	1.85	#DIV/0!	1.64	2.40	1.62	1.60	1.71	1.60	1.69	2.00	1.72	1.65	1.89
0.75	1.94	1.91	#DIV/0!	1.79	3.50	1.78	1.40	1.83	1.40	1.82	2.75	1.84	2.00	1.93
1.00	2.00	1.94	2.00	1.87	#DIV/0!	1.86	1.00	1.89	1.00	1.89	9.00	1.90	2.20	1.95
1.25	2.10	1.96	2.00	1.91	#DIV/0!	1.91	0.60	1.93	0.60	1.92	2.33	1.93	1.80	1.96
1.50	2.13	1.97	2.00	1.94	-0.50	1.94	0.40	1.95	0.40	1.95	2.50	1.95	2.50	1.97

Model Vars:

T	0.9	0.3	0.3	0.6	0.3	0.6
sigma 1	51	79	70	36	40	53
sigma 2	250	42	31	33	62	1460

	NE12-23-07- W3M Riverhurst Hole 5	NW24-23-07- W3M Riverhurst Hole 1	NW24-23-07- W3M Riverhurst Hole 3	NW24-23-07- W3M Riverhurst Hole 2	NW24-23-07- W3M Riverhurst Hole 2	S1/2 24-10-26- W3M Maple Creek Hole 2	S1/2 24-10-26- W3M Maple Creek Hole 3
	Well-defined two-layer earth	Poorly defined two-layer earth	Poorly defined two-layer earth	Modeled as homogenous	Modeled as two- layer	Extreme two- layer case	Extreme two- layer case
Comments:	In this well defined case, the two layer approximation worked well in the region of high validity (unshaded).	The H reading went to 0 too quickly to provide a useful comparison.	Although the trend matched, again the H reading approached 0 too rapidly. Even by 0.5m height, we are dealing with relative error clearly well over tolerable levels.	This hole was nearly homogenous with only a slight negative conductivity trend with depth. Neither model represented the actual case with much success, again due in part to the overall low apparent conductivity readings (high relative error).		The trend follows correctly and values are reasonably well defined for the subtle change, but still break down rapidly beyond 50cm height.	The model predicts a less extreme change with height than is observed. This is because the top 30cm is more conductive than the second 30cm. Aside from that, we see good coherence.

In this study we were trying to determine whether the ratio of the measured vertical to horizontal conductivity (V/H) at any height can be used to predict whether conductivity is increasing or decreasing with depth.

Our observations regarding multi-height modelling are as follows:

- In a more resistive earth, there is less tolerance for determining changes with conductivity with depth if the instruments are high above the ground. This is because the apparent conductivity values are already low, and raising the instruments reduces them further dramatically increasing the relative error of the instruments.
- The greatest ratio changes occur within the first 0.6m of soil. Beyond 0.6m, the two readings (V and H) are rapidly converging on a 2:1 ratio. This means that from theory alone, raising the devices above ~0.6m will result in ratios at or very close to 2:1 regardless of the absolute conductivity and regardless of any layering. So while the two devices will each provide information about absolute conductivity levels, they will not provide information that is different from each other (beyond the 2:1 ratio defined by the response curves).
- In drill holes where the earth is well approximated by a homogenous earth or by a two-layer earth, there is a strong correlation between the observed ratio and the modeled ratio (using whichever is most appropriate). In cases where the change is not as well defined, there is no correlation whatsoever.
- There appears to be a problem inherent in using 30 cm core thicknesses when testing the accuracy of above surface EM measurements. Both the vertical and horizontal EM38 devices have already peaked by 0.3m and by 0.6m their ratio value has already become close to the converging value of 2:1. In other words, the spacing of the lab tests on the drill cores (30cm sections) is not well suited for layer analysis with the EM38. Height-varied layer identification through the use of ratios is best suited for depths only down to ~0.6m, so with layers limited to 0.3m, very little differentiation through the use of ratios is even possible. The EM31 would be better suited to identifying 30cm-thick layers in this depth range.
- In conclusion then, the results are about as we could have hoped for given that the lab-defined sections were not well suited to the instruments used to collect the data. They worked well when there were two clearly defined layers at a 30 cm intervals. Our models have helped us estimate variations in subsurface conductivity patterns with depth.

Search for aquifers using the EM34 on the precision frame

In 2010 we extended the modelling work that we began in 2009. Modelling helped us to determine what the subsurface water situation was in Manitoba, which has been discussed in the previous section (Search for Aquifers Using the EM34 on the Precision Frame).

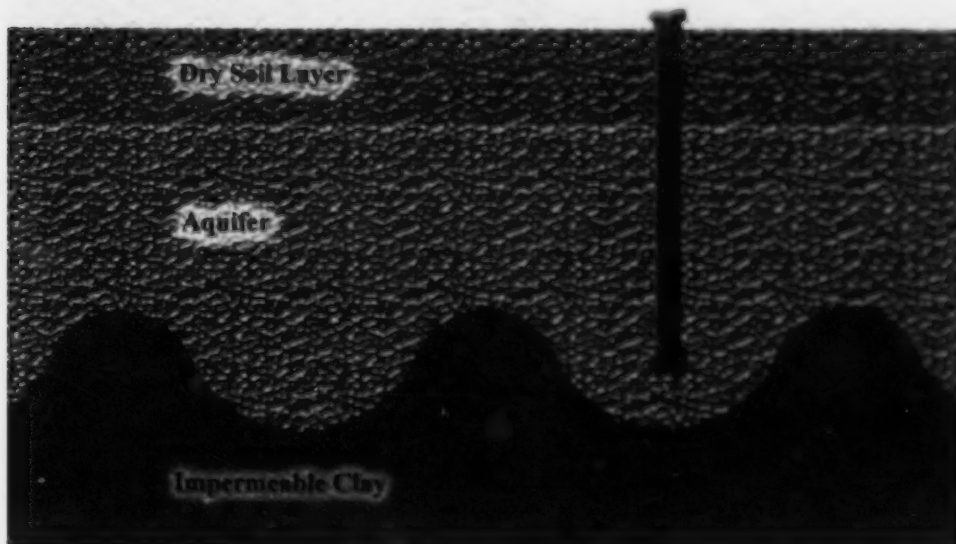
In 2009 we had successfully mapped near-surface aquifers using the EM38 and EM31 systems. These instruments can find aquifers that are within about 1.5 and 6 meters of the surface. The EM34 has a penetration depth of approximately 15 meters. We were interested in testing the EM34 system in areas where the ground water was below the penetration depth of the EM38 and EM31 instruments.

We had an opportunity to do this during the winter of 2009/10. AESB personnel in Manitoba were interested in drilling a well in a rural aquifer. This well would be used by local tankers to supply water to nearby agricultural producers. AESB personnel from Regina surveyed the requested area using the EM34 attached to the precision frame. Drilling was carried out as the EM survey was in progress.

This water survey presented us with completely unexpected results. In some areas the conductivity readings were high, indicating the presence of water. In other areas conductivity readings were low. Follow up drilling indicated that the aquifer had a limited depth extent. Based on our analysis we believe this aquifer provides sufficient water during the spring and summer months, but that the flow rate drops substantially during the fall.

We came up with the following interpretation of the data.

Figure 42
Spring and early summer - high water table

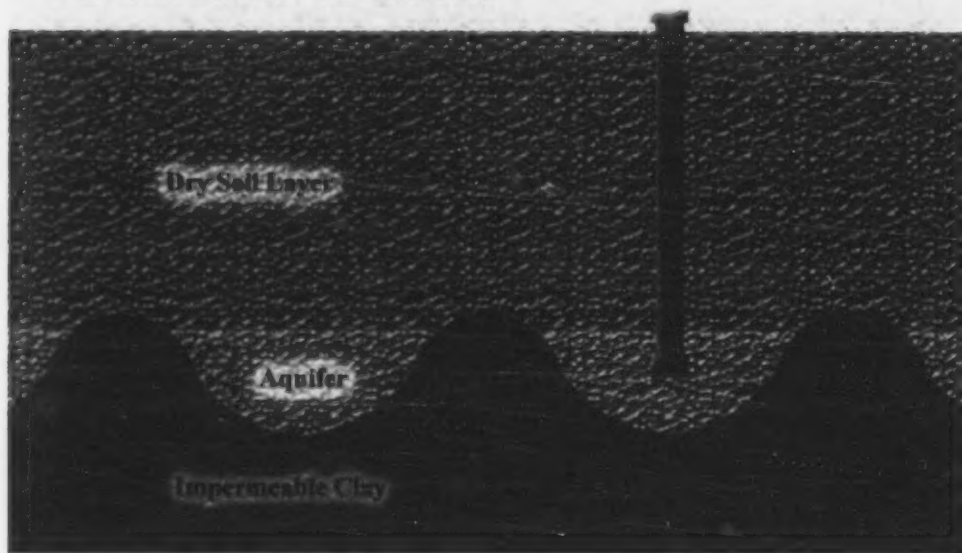


Recharge of aquifers is highest during spring and early summer. Water levels are highest during this time, and then drop during the remainder of the year. If the bottom, impermeable layer is horizontal, then the water level will drop uniformly over the area. If the bottom layer has high and low areas, as shown in the picture above, the situation changes dramatically.

In the following figure the water table has dropped considerably. Water in each buried lake is no longer connected to water in other lakes. As water is pumped out of the well at the right, the water will drop in that lake, but not in neighbouring lakes. As a result two things can occur: flow rates from the well drop, and the well on the right may dry up once the water in the local buried lake has been pumped out. This well will remain dry until recharge occurs in the spring.

Figure 43

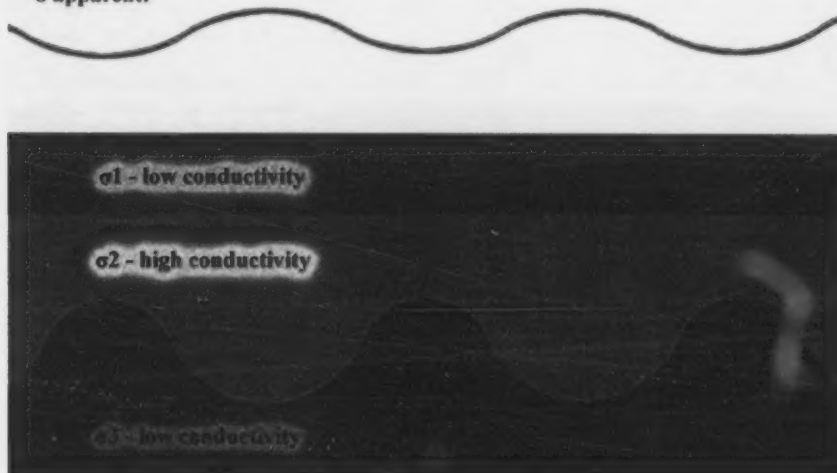
Late summer and fall - low water table



We have developed conductivity models to describe this situation.

Figure 44: Apparent conductivity at the surface during spring and early summer

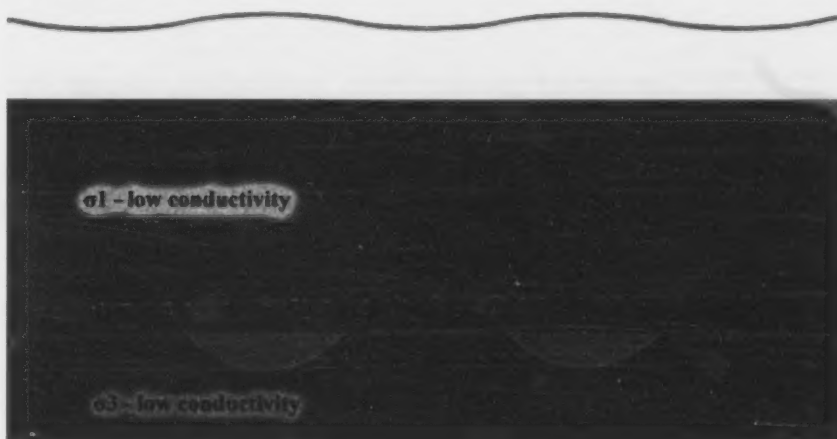
σ apparent:



The topsoil and clay have lower conductivity values than the water-filled soil. As a result, conductivity values at the surface will be greater where the aquifer is thicker. As the water table drops, some locations will have no subsurface water, and surface conductivity values will be low. Conductivity values over these underground lakes will also be lower than during the spring, but still higher than nearby areas where the aquifer has been cut off.

Figure 45: Apparent conductivity at the surface during late fall and winter

σ apparent:



spring or summer may indicate that a well is producing an adequate supply of water, but in fall and winter the aquifer may become a small underground lake. A well placed in such a location may have a very low water output, or may dry up completely.

Recommendations

Prior to drilling a well, an EM34 survey should be carried out over the area thought to contain an aquifer. If the apparent conductivity has ups and downs as in Figures 44 and 45, then a buried lake situation may occur in summer or fall. Test drilling should be carried out in winter to determine flow rates, and/or the presence of water where conductivity highs appear. If flow rates are low or if there is no water present during the winter, a different site should be chosen as a rural water supply.

We also recommend that ATVs should be replaced by cab units that contain heaters. This Manitoba survey was carried out in the winter, and a change in the weather made conditions very difficult for the ATV operator.

We have been primarily concerned with using ground conductivity readings to detect underground water. However the same technology can be used to find areas where there is no water. AESB is using the EM34 system in the precision frame to find carcass burial sites in western Canada. In this situation AESB is looking for sites where groundwater is not close to the surface.

Inversion of electromagnetic Field Data

Our electromagnetic surveys are primarily aimed at determining the conductivity and layering of the near-surface geology. From the survey data we are attempting to answer three questions:

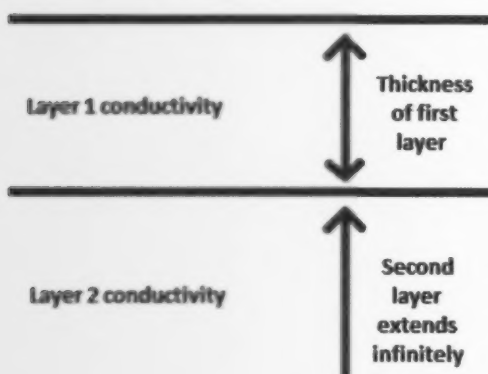
- How many layers are present in the sub-surface?
- How thick is each layer?
- What is the conductivity of each layer?

The algorithmic process of answering these questions is called *inversion*. This process involves taking surface electromagnetic readings and using mathematical methods to estimate how conductivity changes with depth. Inverted data can then be combined with theory and field information to derive more directly applicable knowledge about the hydrogeology of the survey area.

Inversion of EM survey data is particularly complicated and is still an evolving area of research. The source of its complication is that for any one element of survey data, there are a large number of ways that subsurface conditions (the number of layers, and the thicknesses and conductivities of these layers) can result in the measured value at the surface. The more survey data available for a given survey point, the more we can exclude less likely results. Inversion algorithms are consequently extremely computationally intensive and can be quite time-consuming (they can take days on even a small survey with modern computers). The real trick in the inversion process is then to know what possible causes can be disregarded to reduce the possibilities under evaluation.

The more survey data obtained from more clearly defined depths, the more accurately an inversion algorithm can determine the precise details of the layer structure and conductivity. This point is a motivating factor for using multiple devices in EM surveys. Since most of the literature is only discussing inversion of data from a single device, it was important for us to do our own investigation for our unique situation, and we hoped, with greater success.

Figure 46: Two layers, three unknowns



The simplest way to theoretically solve such a system is to match the number of unknowns in the solution to the number of data points available. Figure 46 shows a very simple two-layer model. A two layer earth has three unknowns: the conductivity of each layer and the thickness of the first layer. The thickness of the second layer is taken to be infinite, and so is "known". This pattern is the same regardless of the number of layers, such that a three layer earth will have five unknowns, a four layer earth seven unknowns, and so on. For the model of Figure 46, there are three unknowns, so we can in principle solve this situation if we have three pieces of data.

This method of solution uses a simple linear algebraic technique and is one of the least computationally intensive methods of finding a solution. Unfortunately we found that it has some limitations.

If only three devices are available for the survey, this method is limited to the assumption of a two-layer earth – an assumption which may or may not be correct. Our early mathematical models showed that this assumption resulted in deviations to the solved thickness of the first layer. This effect was more pronounced the more layers were present, and increased with greater conductivity contrast between layers. Finally, we also noted that if an even number of devices was available for survey, it did not match the number of unknowns which would always be an odd number. Thus we had more information than this technique was capable of making use of.

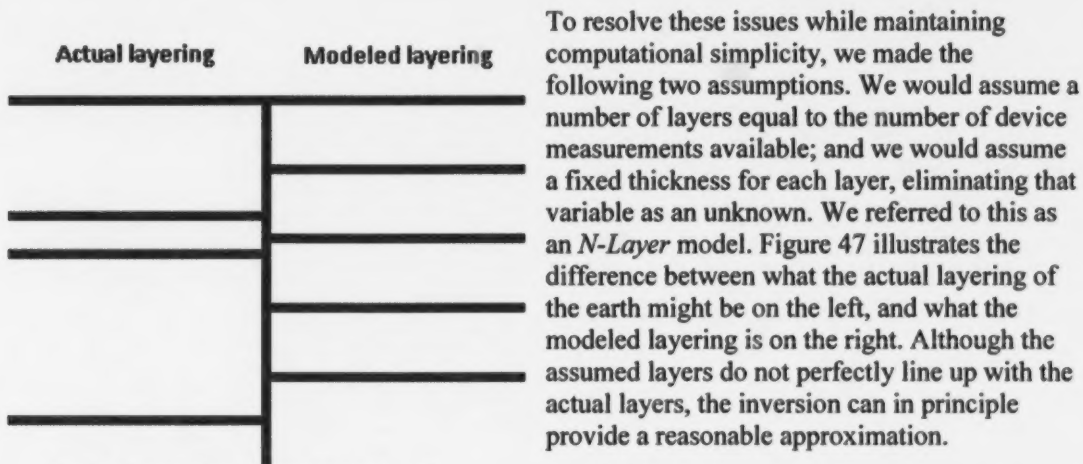


Figure 47: Comparison of actual layering with assumed layering in N-layer analysis.

To resolve these issues while maintaining computational simplicity, we made the following two assumptions. We would assume a number of layers equal to the number of device measurements available; and we would assume a fixed thickness for each layer, eliminating that variable as an unknown. We referred to this as an *N-Layer* model. Figure 47 illustrates the difference between what the actual layering of the earth might be on the left, and what the modeled layering is on the right. Although the assumed layers do not perfectly line up with the actual layers, the inversion can in principle provide a reasonable approximation.

There has been some limited success by other groups using N-layer models with more computationally intensive inversion algorithms that rely on only a single data source. Our thinking was that additional data sources (more devices, or a single device at more heights) would increase the success of N-layer inversion while dramatically reducing computational intensity.

This method proved quite successful regardless of the number layers involved, but it was important to test it under more realistic conditions instead of the idealized data generated for the apparent conductivity from a computer model. Real-world data will contain some degree of measurement error, so we took the exact apparent conductivities generated by the model and applied a statistical variation to them such that they were between -3% and +3% of their true values. This small variation to the exact values resulted in extremely divergent solutions. An error of as little as 0.5% could produce a variation as high as 200% in the solved conductivity of a particular layer.

The cause of the dramatic deviation is in the nature of the equations themselves. In linear algebra, there is a concept called *stability* which refers to the sensitivity to value variance for any

system of equations. The equations involved in solving EM data using induction methods inherently produce highly unstable systems of equations.

Dealing with unstable systems of equations is not simple, however in some cases it can be sufficiently compensated for by using an *over-determined set*. This technique requires more data for a given point than there are solutions, as opposed to matching the number of datum to the number of layers as was done in previous methods. The extra data is then interpolated, or *smoothed*, in order to eliminate as much error as possible. The interpolation process is quite a bit more computationally intensive, but still much faster than other techniques.

The next model we developed used an over-determined set (data from the EM38 at 7 separate heights) derived from a three-layer earth to provide the input for an N-layer inversion model of three layers. This method dramatically decreased the sensitivity of the system, but not enough. The same $\pm 3\%$ error distribution applied to generated apparent conductivity values produced about a $\pm 80\%$ deviation in the solved conductivity values – extreme enough that from one run to the next it was clear this method would not give us any useful data.

Our work in this area in 2009 and 2010 indicates that the least computationally intensive methods are not an option when trying to determine subsurface conductivity from surface values. We have been investigating an inversion method using what is called a “genetic algorithm”. We were briefly introduced to this method in 2009 by Robert Petrie, a PhD graduate from the University of Regina. Dr Petrie has used this method to analyze data that is more complex than what we are currently dealing with. We have also conducted a literature search and have discovered that in the last few years individuals have successfully used the genetic algorithm to predict subsurface conductivity variations measured with resistivity instruments (Akça et al, 2010, Basokur et al, 2007, Singh, 2005). It is highly likely that this method will also work with conductivity variations measured with conductivity meters.

LITERATURE REVIEW: AIRBORNE ELECTROMAGNETICS IN THE SEARCH FOR FRESH WATER

Groundwater supplies in Saskatchewan are mainly located in bedrock aquifers, pre-glacial buried river valleys, and buried glacial valleys. The buried river valley and glacial valley aquifers are often found close to the surface, and are easier to find using electromagnetic methods than deeper bedrock aquifers.

During the last ice age a large number river valleys within Saskatchewan were filled in with sand and gravel. "The buried valleys tend to be broad, usually three to 15 kilometres (km) wide, with gently sloping sides. Buried valley aquifers are typically between 30 and 90 m thick and are covered by 30 to 90 m of drift, mainly till" (SAFRR, 2005). Such aquifers are capable of delivering 10-50 litres/second from a single well.

During the ice age, glaciers cut steep, narrow valleys into the existing soil. The bottom of many of these glacial valleys contains sand or gravel, which can carry water. Typical yields from wells in Saskatchewan's glacial valleys are 10-20 L/s.

The large pre-glacial buried river valleys have been extensively mapped; the narrower glacial valleys less so.

In 2009 we reviewed the literature on locating fresh water sources using airborne electromagnetic methods. We also met with Flemming Jørgensen, with the HydroGeophysics Group, University of Aarhus, Denmark. Dr. Jørgensen is a hydrogeologist who has been at the forefront of using airborne electromagnetics to detect buried glacial valleys in Denmark. I also met with Dr. Richard Smith of Laurentian University. Dr. Smith previously worked with Fugro, a major international geophysical survey company. Fugro used their own airborne electromagnetic system to find water in buried glacial valleys in Denmark.

A subsequent review of the literature showed that the airborne electromagnetics has been successfully used to discover underground water sources in a number of countries. The Danish experience is of most interest as there are many similarities between Danish and Saskatchewan glacial geology.

The research conducted by the University of Aarhus employed the SkyTEM system, which consists of a helicopter borne electromagnetic transmitter and receiver (see the following two figures).

Figure 48: The SkyTEM helicopter borne electromagnetic transmitter and receiver

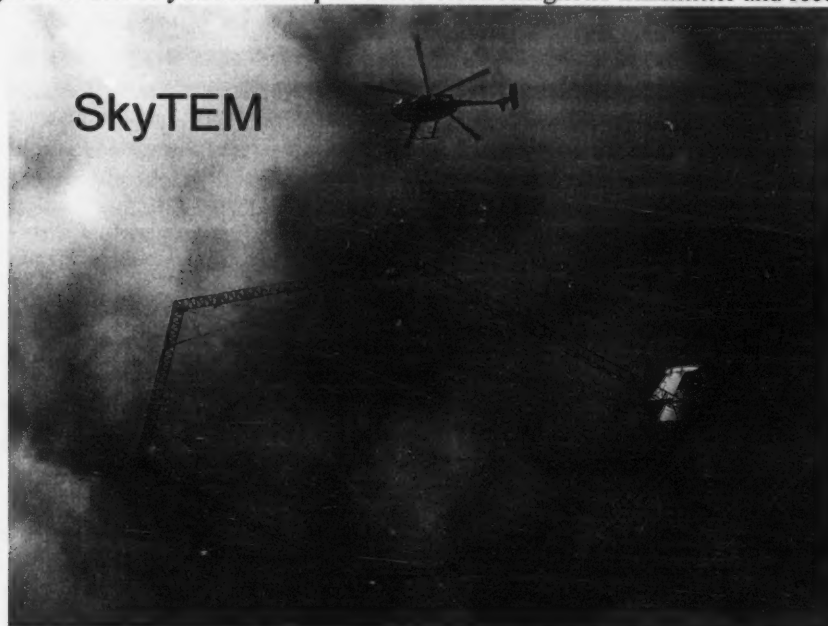
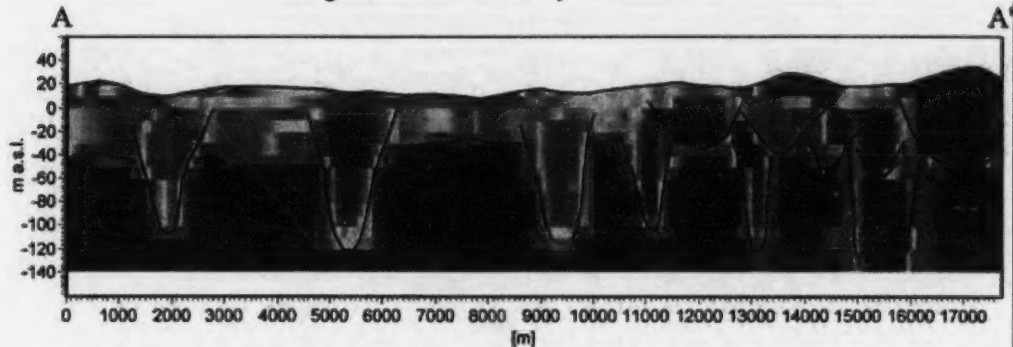


Figure 49: Surveying with the SkyTEM system



The following diagram demonstrates how the electromagnetic method is used to locate buried valleys. In many areas of Denmark the glaciers carved valleys out of highly conductive clays. In many areas these valleys were filled with sand and gravel. Sand and gravel has a lower conductivity than the clay, and as a result the valleys stand out as low-conductivity anomalies. In the diagram below these glacial valleys stand out quite well. In some cases there have been multiple glacial events, and some buried valleys have cut through pre-existing buried valleys.

Figure 50: Buried valleys in Denmark

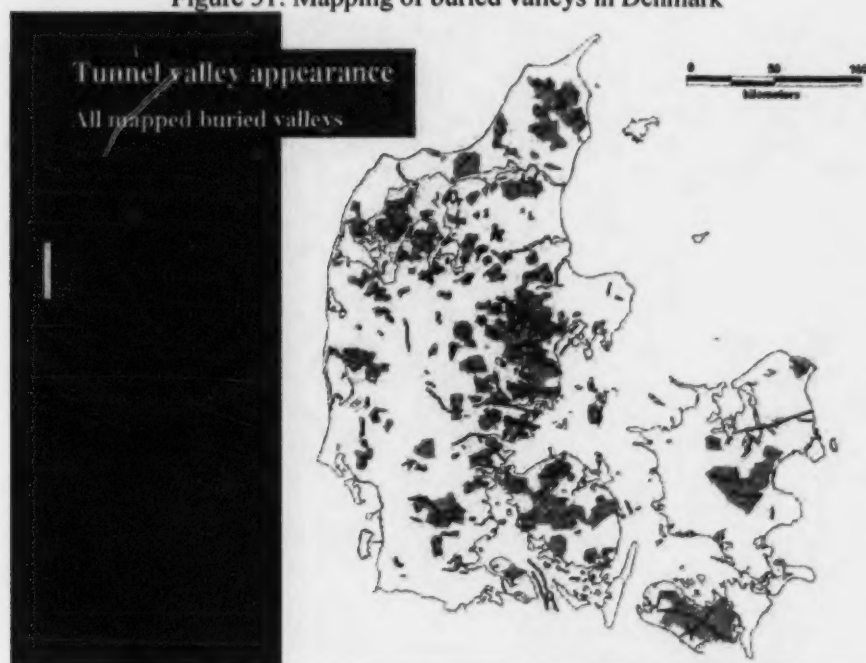


Courtesy Dr. Flemming Jørgensen, University of Aarhus

The above cross-section is shown at a large scale. More detail is available when the information is plotted at a smaller scale. This diagram contains the conductivity with depth values for a single helicopter pass over an area. Typically multiple passes are made over an area, with a typical distance of 100-200 metres between each pass. This makes it possible to create three dimensional subsurface conductivity maps.

In Denmark the preliminary electromagnetic mapping of buried glacial valleys was so successful that the Danish government extended the mapping program to cover the entire country. The Danish government paid for this mapping by charging approximately 0.01 ¢ per litre on water consumption. Some of the results of the glacial valley mapping program are shown below.

Figure 51: Mapping of buried valleys in Denmark



Courtesy Dr. Flemming Jørgensen, University of Aarhus

The 3D nature of the conductivity map allows us to estimate the size of the recharge area. An example of this can be seen in the green inset area in the figure above. It is possible to trace the various interconnections between underground river valleys, and locate the various recharge areas.

The depth of penetration of the SkyTEM system is between 200 to 300 meters, unless the water is very saline. In this case the depth of penetration of the system is approximately 100 meters below the surface. This depth of penetration is well suited to locating both buried river valleys and glacial valleys in Saskatchewan. The SkyTEM system can typically resolve up to 5 horizontal, lithological units. This resolution has made it possible for hydrogeologists to determine whether low conductivity sand and gravels (a requirement for the presence of an aquifer) can be found at the bottom of these buried valleys. This information is extremely useful in determining where to site water wells. Drilling wells is expensive, and so the electromagnetic surveys will be used to determine where the wells should be sited, and how deep they will need to be drilled in order to reach the sand/gravel layer at the bottom of the glacial valley.

We believe that these glacial aquifers may provide many new sources of water in the province. While water sources in glacial valleys have been found in both Saskatchewan and Alberta using other methods, the number of undiscovered sites is potentially large. Airborne electromagnetic methods may be a cost effective way of mapping these values, and we recommend that a test electromagnetic survey be carried out.

In April of 2010 I met with Max Halkjaer, managing director and geophysicist of SkyTEM ApS, an international electromagnetic survey company that is based in Denmark (www.skytem.com). A SkyTEM survey in Saskatchewan could be carried out in an area where buried glacial valleys either known or suspected to exist. Existing geological and hydrogeological maps would be used to select a test area. The direction of flight would be at 90 degrees to the suspected path of the buried channel. Successive helicopter flights would be conducted at line a spacing approximately 200 meters apart. This will provide sufficient detail to determine the location of buried valleys.

The total area covered by such a survey would be approximately 100 sq kilometres. It will be possible to survey two smaller areas as long as the distance between the two areas is less than 200 km. If the distance is greater, the survey may take an extra day, and there would be an additional cost for this time.

We would choose the test area or areas to be covered by such a survey. We can pick locations where there are known aquifers, and we can then determine if the SkyTEM system can accurately locate them and estimate their depth.

Max Halkjaer and I have made a preliminary cost estimate for such a survey:

Estimated cost of an airborne electromagnetic survey

Mobilization/demobilization	\$32,000
Flying 500 kilometres @ \$135/line-kilometre	67,500
Provision of flight data and report	5,000
Detailed inversion, 500 km @ \$27/line-kilometer	13,500
Total survey cost	\$118,000

Details of mobilization costs

- Transfer of EM crew and equipment to survey base site
- Cost of ferrying a locally hired helicopter and crew to survey base site
- Purchase and ferrying of helicopter fuel to survey base site
- Attachment of EM and other equipment to helicopter
- System testing and calibrations

Details of demobilization costs

- Removal of equipment from helicopter and packing equipment
- Shipping equipment
- Transport of survey personnel
- Transport of helicopter and flight crew

The detailed inversion costs include removing the effects of interference due to metal in fences, underground pipes, roads, etc. It also provides a more detailed analysis of the subsurface structure than is provided in the regular report. Our company could carry out this detailed inversion, but we believe that it would be more cost effective to have it done by SkyTEM.

Conclusion: We recommend that a test survey be carried out in Saskatchewan over buried valleys.

RESEARCH OBJECTIVE 4

Proof of concept of the seismoelectric method

We were unable to meet this objective. We conducted a literature review in the field, and we were able to analyze one test site which AESB had commissioned prior to the start of this project.

We ran into serious difficulties in scheduling the activities of the Alberta based contractor who conducts seismoelectric surveys, AESB hydrologists/geologists, and AESB field reps that would need to be present at the test sites.

A number of test sites were developed where we had unpublished information available to us regarding the depth and quality of water. Some of these sites had to be discarded at the last minute due to conditions over which we had no control, such as flooded fields.

Coordination of the activities of the contractor and AESB field staff was undertaken by one of our partners at AESB. This individual transferred to a different department during the research period, and was unable to continue working on this project. We tried to take over this coordination task, but unfortunately we did not have the contacts that were needed in order to successfully bring this process to completion.

RESEARCH OBJECTIVE 5

Investigate the potential benefits of using conductivity meters other than Geonics instruments

One of the goals of our research project was to compare the various types of ground-based electromagnetic systems that are available on the market, and attempt to determine which of these would be most suitable for locating new supplies of fresh water. We have reviewed the available professional and academic literature, read a number of the manufacturers' technical documents, and have corresponded with technical personnel at various companies.

The use of ground-based electromagnetic devices provides information that is useful for determining near-surface geology, which is an important contribution to our understanding of the distribution of fresh water. Of particular interest is the *electrical conductivity* (EC, or simply *conductivity*). EC can be used to indicate salinity, soil moisture content, the type of soil, and various other attributes. (Brevik 2006; Corwin 2005) There are a variety of devices available that measure soil conductivity and a part of our project is to determine which of these products is most suitable for our purposes.

The ability to distinguish both lateral and vertical changes in conductivity has particular relevance for groundwater investigation. (Brevik 2006; Triantafilis 2005) The ability of a device to 'see' into the ground – its *depth penetration* – is a complex function of its orientation, the frequency at which it operates, the size of the device, and the conductivity of the soil. By altering these variables – size¹ and frequency – we can obtain information derived from different layers.

Figure 52 shows how this is achieved with two pieces of equipment we currently employ. The two devices have peak responses at different depths indicated by the peak of their respective curve. If there is a layer change at 1m for example, the two devices will report values indicating the change.

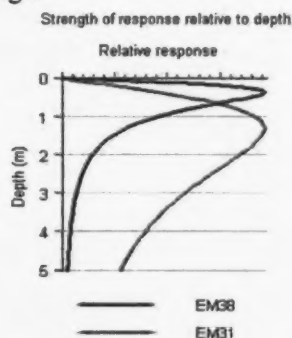


Figure 52: The bulk of the EM-38 response is above 1.5m. The equivalent response range for the EM-31 extends much deeper.

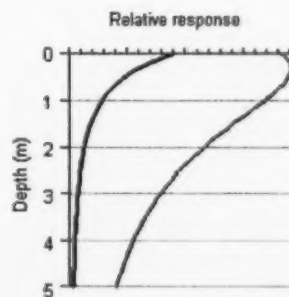


Figure 53: Devices raised to 1 metre.

¹ Here size refers to the distance between the transmitter and receiver of the device.

Another way we can gain information about the layering of the soil is by raising the devices into the air. (Morris 2009) This raises the peak of the response curve to some different layer of soil. If there is a change in true conductivity between these layers, the apparent conductivity reported by the device will reflect this. Figure 53 illustrates the characteristic responses of the two devices from Figure 52 raised to a height of 1 metre.

Up to now, we have primarily used three products from Geonics Ltd of Mississauga Ontario; the EM-38, EM-31, and EM-34. These three have a fixed depth penetration due to their fixed size and operating frequencies; 1m at 14.6kHz, 3.67m at 9.8kHz, and 10m at 6.4kHz respectively.²

There are now other products available, in particular the Aeroquest (formerly Geophex) GEM2 which is a handheld device similar to the EM-38 in size (it is 1.6m in length) but which operates at frequencies from 330Hz to 48kHz.³ Because depth penetration depends on both size and frequency, the depth penetration of the GEM2 is not fixed as it is with the Geonics equipment. Aeroquest claims depth penetration as high as twenty to thirty metres depending on the frequency chosen. The GEM2 also operates multiple frequencies simultaneously, providing separate streams of information from different depths.

DUALEM of Milton Ontario is a third company manufacturing these devices that we evaluated. From a technical perspective their products appear to be quite similar to Geonics offerings. Unlike Aeroquest, DUALEM and Geonics use a single transmission frequency. As a result interpretation methods are similar for these two systems. Many of DUALEM's instruments combine multiple sensors together for a much lower price than if buying them separately. Depending on the model DUALEM's multi-sensor devices can provide 2, 4 or 6 sensors, each with a different depth of penetration. As a result a single instrument could replace the 2 or 3 instruments that we currently use for a survey. This could be quite useful in our applications, and may potentially reduce costs.

² The EM-34 has additional modes of operation at 20 and 40 metres, but we do not use these in our surveys.

³ Aeroquest's device specifications indicate a frequency range of 300Hz to 96kHz whereas their operating manual indicates a range of 330Hz to 48kHz.

Figure 54: DUALEM 421 Ground Conductivity Meter



We purchased a DUALEM 421 instrument in 2010, and received it in December. We have attached a netbook computer to the instrument, and have successfully carried out several surveys. The advantage of the DUALEM 421 is that it combines the functions of the Geonics EM31 and EM38. There is no interference between the 6 sensors in the instrument, as there is between the EM31 and EM38 instruments if they are too close together. Only one frame needs to be constructed to tow or carry the instrument.

The following discussion only compares the Geonics and Aeroquest instruments.

With respect to ease of operation, all of the devices are quite similar. The EM-31 and EM-34 require some on-site assembly prior to usage because of their larger size, whereas the EM-38 and GEM2 are a single piece requiring no further assembly. The Geonics devices have short zeroing procedures, and the GEM2 requires the user to choose the frequencies of operation. All four devices have a display indicating the current reading and ports for connection to a computer.

The quality and interpretability of the data is where we find divergence between the two companies' devices.

First it must be understood that none of the devices directly measure the actual conductivity of the soil. They measure the strength of a received signal that is heavily dependent on the conductivity of the soil within a particular volume. What volume is determined by various parameters as discussed above. But there is an important complicating factor here. The overall strength of the response itself is also a function of both frequency and soil conductivity. Changing frequency not only changes the depth penetration, but also the degree to which the soil responds to the generated signal. (McNeill 1980)

The Geonics devices we currently use are highly calibrated for ranges of soil conductivities that are typically found. For each device, Geonics has selected a particular frequency such that the

on-board software can translate the measured signal strength into a value referred to as *apparent conductivity*, a number which is a close approximation to the average true conductivity of the soil within that characteristic volume. Different devices operating at different sizes and frequencies will then require different precise calibrations in order to provide an accurate apparent conductivity.

Because Geonics devices all output this apparent conductivity as opposed to the strength of the signal they are measuring, outputs from multiple Geonics devices can be directly compared with each other and with conductivity information gathered from other sources. This makes interpretation of data very straight forward and identification of horizontal strata possible through the use of multiple devices.

The GEM2 (and other Aeroquest EM devices) operates over a range of multiple frequencies set by the user *at the time of survey*. As a result, the same careful calibration that Geonics does cannot be performed here since there are too many other unknowns. The only way such a calibration would be possible is if the actual conductivity and layering of the soil at the survey site were already precisely known to the operator using some other technique – in which case there would be no need to repeat the survey with the GEM2.

Without this calibration, the GEM2's output is not equivalent to conductivity at any frequency (except by pure chance) and the depth penetration of each user-chosen frequency cannot be precisely known. Consequently it is not physically possible to identify the depth and thickness of layers, the *actual* conductivities of those layers, or to compare *relative* conductivity variations between layers (vertical variation). All that can be identified using the GEM2 is *relative horizontal conductivity variations of multiple layers at unknown depths*. Such results can easily be mistaken for absolute horizontal and vertical variation by those unfamiliar with the complex underlying physics.⁴ It should also be mentioned that such results may still be useful for some applications, but they are not useful for our application.

In summary then, the current devices in employ (the Geonics EM-38, EM31, and EM-34) when used on their own or in combination provide data of a high degree of confidence within a well-defined set of parameters. The company acknowledges physical limitations and goes out of its way to ensure users of their equipment are aware of these limitations. When used in combination, additional information (over and above that provided by any one device) becomes available and delineation of layering within the earth becomes possible, which is essential to this project. The GEM2 provides more information than any one Geonics device, but that information is of less relevance and lower confidence.

Conclusions

The Geonics electromagnetic systems have shown their usefulness for a number of applications, including the search for water supplies. We have far less confidence in the GEM2 system for the reasons provided above. We have decided to use the DUALEM 421 instrument as it appears to be a major improvement to the Geonics devices.

⁴ According to their website, Aeroquest maintains that the GEM2 *can* be used to resolve both vertical and horizontal conductivity variations (depth sounding). This is a subject of some debate in the literature. (Pellerin and Wannamaker 2005)

Administration

Personnel involved

Evan Morris	EcoTech Research Ltd
Sean Sunley	EcoTech Research Ltd
Alex Clarke	EcoTech Research Ltd
Chris Hill	AESB
Grant Cranfield	AESB
Nadeen Brossart	AESB
Rose Patterson	AESB
Vic Klassen	AESB
Garth Weiterman	Irrigation Branch, Saskatchewan Ministry of Agriculture
Syed A Imran	NRC Centre for Sustainable Infrastructure Research, Regina

Project materials developed

We have developed a computer program that reads data simultaneously from four electromagnetic instruments and from a GPS receiver.

We have designed and constructed a precision carrier to attach an EM34 instrument to an ATV.

We have designed and constructed a precision carrier to attach an EM31 instrument to an ATV.

We have developed a number of computer models that can be used to analyze subsurface conductivity conditions.

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APPENDIX 1A

Interference tests of ATV on the EM-31 instrument

EM-31 readings are made at one location, but at several heights using the ladder.
The quad is then brought closer and closer to the ladder, and the readings are repeated.

Case 1 - centre of quad parallel to centre of EM-31

TI = transmitter at front of quad

RI = receiver at front of quad

Height	No ATV	TI 0.34 m	TI 0.78 m	RI 0.78 m	TI 0.34 m	TI 0.78 m	RI 0.78 m
0.62	107	150	134	135	40%	18%	21%
0.76	101	139	125	127	38%	17%	21%
0.92	95	127	115	119	34%	16%	21%
1.07	90	113	105	108	26%	13%	17%

Errors

% Errors

Height	TI 0.34 m	TI 0.78 m	RI 0.78 m
0.62	43	27	28
0.76	38	24	26
0.92	32	20	24
1.07	23	15	18

Case 2 - quad is moved forward, DeltaX = 0.34 m

Height	No ATV	TI Y=0.0m	TI Y=0.40m	TI Y=0.70m	RI Y=0.18m	RI Y=0.34m	RI Y=0.48m	RI Y=0.67m
0.62	107	150	151	154	151	151	154	154
0.76	101	139	143	146	143	142	145	149
0.92	95	127	125	125	130	133	132	136
1.07	90	113	112	112	114	118	115	118

Errors

Height	TI Y=0.0m	TI Y=0.40m	TI Y=0.70m	RI Y=0.18m	RI Y=0.34m	RI Y=0.48m	RI Y=0.67m
0.62	43	44	47	44	44	47	47
0.76	38	42	45	42	41	44	48
0.92	32	30	30	35	38	37	41
1.07	23	22	22	24	28	25	28

% Errors

Height	TI Y=0.0m	TI Y=0.40m	TI Y=0.70m	RI Y=0.18m	RI Y=0.34m	RI Y=0.48m	RI Y=0.67m
0.62	40%	29%	31%	29%	29%	31%	31%
0.76	36%	28%	30%	27%	27%	29%	31%
0.92	30%	20%	20%	23%	23%	25%	27%
1.07	21%	15%	15%	16%	19%	17%	18%

Case 3 - quad is moved forward, DeltaX = 0.78m

Height	No ATV	TI Y=0.0m	TI Y=0.33m	TI Y=0.72m	TI Y=1.08m	RI Y=0.0m	RI Y=0.33m	RI Y=0.72m	RI Y=1.08m
0.62	107	134	134	135	131	135	136	135	136
0.76	101	125	125	127	123	127	127	128	130
0.92	95	115	114	112	111	119	118	119	117
1.07	90	105	105	102	100	108	109	110	108

Errors

Height	TI Y=0.0m	TI Y=0.33m	TI Y=0.72m	TI Y=1.08m	RI Y=0.0m	RI Y=0.33m	RI Y=0.72m	RI Y=1.08m
0.62	27	27	28	24	28	29	28	29
0.76	24	24	26	22	26	26	27	29
0.92	20	19	17	16	24	23	24	22
1.07	15	15	12	10	18	19	20	19

%Errors

Height	TI Y=0.0m	TI Y=0.33m	TI Y=0.72m	TI Y=1.08m	RI Y=0.0m	RI Y=0.33m	RI Y=0.72m	RI Y=1.08m
0.62	25%	25%	28%	22%	26%	27%	26%	27%
0.76	24%	24%	26%	22%	26%	26%	27%	29%
0.92	21%	20%	18%	17%	25%	24%	25%	23%
1.07	17%	17%	13%	11%	20%	21%	22%	21%

Interference tests of ATV on the EM-34 instrument – Part 2

Testing done Jun 3/09 @ Regina Research Farm

Level coils no elevation, No ATV:

69 mS/m

ATV length:

2.82 meters (front of current boom to back of current winch)

Approx 2 meters (bumper to bumper)

Note - Approx. 4.0 m distance from coil centre to ATV bumper is the halfway point

ATV distance (x) from Rx coil h's = 0m

Test #	x (m)	Cond. Ms/m	Abs. error	% error
1	0.0	74	5	7%
2	1.0	71	2	3%
3	2.0	70	1	1%
4	3.0	70	1	1%
5	4.0	70	1	1%
6	5.0	70	1	1%

ATV distance (x) from Tx coil h's = 0m

Test #	x (m)	Cond. Ms/m	Abs. error	% error
1	0.0	74	5	7%
2	1.0	73	4	6%
3	2.0	71	2	3%
4	3.0	70	1	1%
5	4.0	70	1	1%
6	5.0	70	1	1%

Interference tests of ATV on the EM-34 instrument – Part 3

Testing done Jun 11/09 @ UofR

Level coils no elevation, No ATV:

61 mS/m

ATV length:

2.82 meters (front of current boom to back of current winch)

Approx 2 meters (bumper to bumper)

Note - Approx. 4.0 m distance from coil centre to ATV bumper is the halfway point

Note - The EM38 boom was on the atv but empty during these tests

Note - In the following data the 38boom was on the ATV which did not allow for 0m (x) observations

ATV distance (x) from Rx coil h's = 1.19m

Test #	x (m)	Cond. mS/m	Abs. error	% error
1	2.0	62	1	2%
2	3.0	62	1	2%
3	4.0	62	1	2%
4	5.0	62	1	2%
5	6.0	63	2	3%
6	7.0	62	1	2%

ATV distance (x) from Tx coil h's = 1.19m

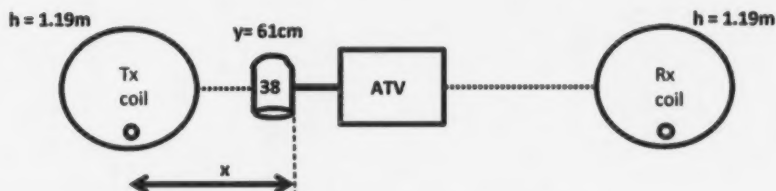
Test #	x (m)	Cond. mS/m	Abs. error	% error
1	2.0	62	1	2%
2	3.0	62	1	2%
3	4.0	62	1	2%
4	5.0	62	1	2%
5	6.0	62	1	2%
6	7.0	60	1	2%

APPENDIX 1B

Interference tests of the EM34 and EM38 instruments

Interaction w/ EM 38

Testing done Jun 11/09 @ University of Regina



Note - the x distance is from the front of the boom to the Rx or Tx coil

EM34 readings with EM38 boom setup, ATV centered

Base reading no 38 in boom: 66 mS/m
 Base reading w/ 38 in boom, turned off: 66 mS/m
 Base reading w/ 38 in boom, turned on: 66 mS/m
 ATV length: 2.82 meters (front of current boom to back of current winch)
 Approx 2 meters (bumper to bumper)

Note - see 3rd data set on ATV worksheet to compare results w/ 38 not in the boom doing atv tests

Note - Approx. 4.0 m distance from coil centre to ATV bumper is the halfway point

EM34 readings with EM38 on, in boom

ATV distance (x) from Tx coil

Test #	x (m)	Cond. mS/m	Abs. error	% error
1	2.0	66	0	0%
2	3.0	66	0	0%
3	4.0	66	0	0%
4	5.0	66	0	0%
5	6.0	67	1	2%
6	7.0	65	1	2%

ATV distance (x) from Rx coil

Test #	x (m)	Cond. mS/m	Abs. error	% error
1	2.0	66	0	0%
2	3.0	66	0	0%
3	4.0	66	0	0%
4	5.0	66	0	0%
5	6.0	66	0	0%
6	7.0	66	0	0%

EM38 readings with EM34 on, in boom

Vertical Dipole Reading = VR

Horizontal Dipole Reading = HR

Note - error is measured from x = 5m where the 38 itself is centered between the coils

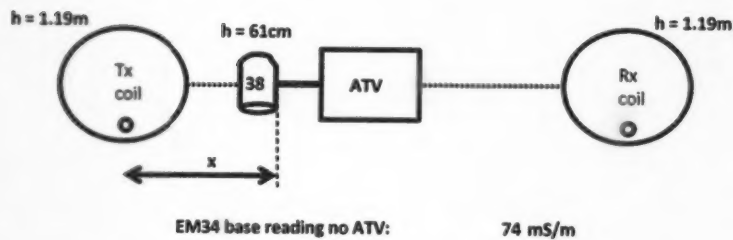
ATV distance (x) from Tx coil

Test #	x (m)	Cond. mS/m	Abs. error	% error	Cond. Ms/m	Abs. error	% error
		VR			HR		
1	2.0	49	11	18%	54	26	93%
2	3.0	54	6	10%	34	6	21%
3	4.0	64	4	7%	32	4	14%
4	5.0	60	0	0%	28	0	0%
5	6.0	60	0	0%	30	2	7%
6	7.0	57	3	5%	28	0	0%

ATV distance (x) from Rx coil

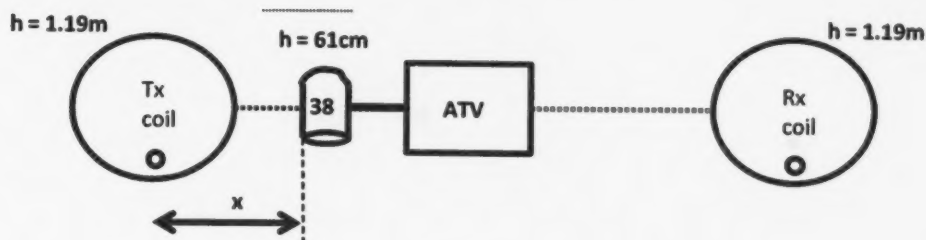
Test #	x (m)	Cond. mS/m	Abs. error	% error	Cond. Ms/m	Abs. error	% error
		VR			HR		
1	2.0	61	1	2%	40	9	29%
2	3.0	57	5	8%	30	1	3%
3	4.0	67	5	8%	37	6	19%
4	5.0	62	0	0%	31	0	0%
5	6.0	62	0	0%	30	1	3%
6	7.0	60	2	3%	27	4	13%

Testing done Jun 16/09 @ Regina Research Farm



- Tests were done with the EM38 on and off taking readings on the EM34XL while moving from as close to the coil as possible to past a centred ATV position
- Tests were done moving the front of the ATV away from each of the coils
- The results showed that the EM38 whether on or off had no effect on the EM34
- The results never only moved from 74 mS/m to 75 mS/m at times which is not significant change

EM38 readings from boom position with the EM34 powered on



Note - error is measured from $x = 5\text{m}$ where the 38 itself is centered between the coils

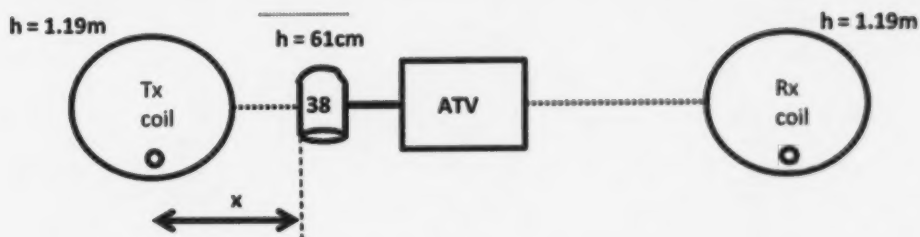
ATV distance (x) from Rx coil

Test #	x (m)	Cond. mS/m	Abs. error	% error	Cond. Ms/m	Abs. error	% error
		VR			HR		
1	0.5	66	2	3%	55	21	62%
2	1.0	64	0	0%	36	2	6%
3	2.0	63	1	2%	32	2	6%
4	3.0	64	0	0%	33	1	3%
5	4.0	63	1	2%	32	2	6%
6	5.0	64	0	0%	34	0	0%
7	6.0	63	1	2%	32	2	6%

ATV distance (x) from Tx coil

Test #	x (m)	Cond. mS/m	Abs. error	% error	Cond. Ms/m	Abs. error	% error
		VR			HR		
1	0.5	53	11	17%	51	18	55%
2	1.0	50	14	22%	42	9	27%
3	2.0	57	7	11%	36	3	9%
4	3.0	66	2	3%	34	1	3%
5	4.0	68	4	6%	35	2	6%
6	5.0	64	0	0%	33	0	0%
7	6.0	65	1	2%	33	0	0%

EM38 readings from boom with the EM34 powered off



Note - error is measured from $x = 5\text{m}$ where the 38 itself is centered between the coils

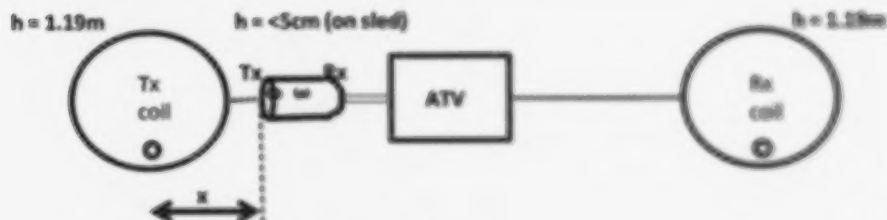
ATV distance (x) from Rx coil

Test #	x (m)	Cond. mS/m	Abs. error	% error	Cond. Ms/m	Abs. error	% error
		VR			HR		
1	0.5	64	0	0%	38	5	15%
2	1.0	62	2	3%	33	0	0%
3	1.5	61	3	5%	31	2	6%
4	2.0	63	1	2%	31	2	6%
5	3.0	63	1	2%	32	1	3%
6	4.0	64	0	0%	32	1	3%
7	5.0	64	0	0%	33	0	0%
8	6.0	61	3	5%	31	2	6%

ATV distance (x) from Tx coil

Test #	x (m)	Cond. mS/m	Abs. error	% error	Cond. Ms/m	Abs. error	% error
		VR			HR		
1	0.5	62	1	2%	188	156	488%
2	1.0	71	8	13%	54	22	69%
3	1.5	67	4	6%	38	6	19%
4	2.0	65	2	3%	34	2	6%
5	3.0	64	1	2%	35	3	9%
6	4.0	65	2	3%	34	2	6%
7	5.0	63	0	0%	32	0	0%
8	6.0	62	1	2%	31	1	3%

EM38 readings from sled position with the EM34 powered on



Note - error is measured from $x = 5\text{m}$ where the SB itself is centered between the coils

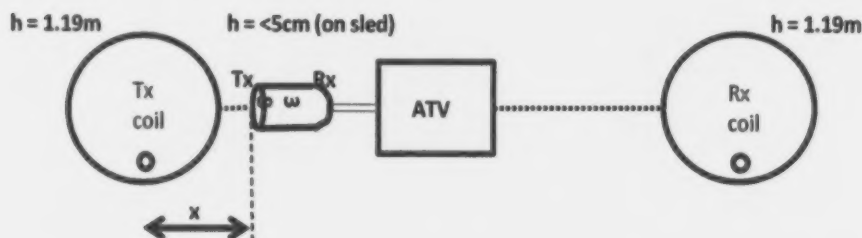
ATV distance (x) from Rx coil

Test #	x (m)	Cond. mS/m	Abs. error	% error	Cond. M _h /m	Abs. error	% error
		VR			HR		
1	0.5	104	5	5%	91	2	2%
2	1.0	106	3	3%	89	0	0%
3	1.5	107	2	2%	90	1	1%
4	2.0	106	3	3%	88	1	1%
5	3.0	108	1	1%	87	2	2%
6	4.0	109	0	0%	87	2	2%
7	5.0	109	0	0%	89	0	0%
8	6.0	111	2	2%	90	1	1%

ATV distance (x) from Rx coil

Test #	x (m)	Cond. mS/m	Abs. error	% error	Cond. M _h /m	Abs. error	% error
		VR			HR		
1	0.5	112	4	4%	100	9	10%
2	1.0	106	2	2%	98	7	8%
3	1.5	111	3	3%	98	7	8%
4	2.0	111	3	3%	98	7	8%
5	3.0	109	1	1%	95	4	4%
6	4.0	110	2	2%	92	3	3%
7	5.0	108	0	0%	91	0	0%
8	6.0	103	0	0%	88	3	3%

EM38 readings from sled position with the EM34 powered off



Note - error is measured from $x = 5\text{m}$ where the 38 itself is centered between the coils

ATV distance (x) from Rx coil

Test #	x (m)	Cond. mS/m	Abs. error	% error	Cond. Ms/m	Abs. error	% error
		VR			HR		
1	0.5	108	2	2%	91	0	0%
2	1.0	108	2	2%	89	2	2%
3	1.5	108	2	2%	90	1	1%
4	2.0	107	3	3%	91	0	0%
5	3.0	109	1	1%	91	0	0%
6	4.0	108	2	2%	90	1	1%
7	5.0	110	0	0%	91	0	0%
8	6.0	109	1	1%	92	1	1%

ATV distance (x) from Tx coil

Test #	x (m)	Cond. mS/m	Abs. error	% error	Cond. Ms/m	Abs. error	% error
		VR			HR		
1	0.5	109	2	2%	100	12	14%
2	1.0	108	1	1%	99	11	13%
3	1.5	109	2	2%	100	12	14%
4	2.0	108	1	1%	98	10	11%
5	3.0	109	2	2%	94	6	7%
6	4.0	110	3	3%	91	3	3%
7	5.0	107	0	0%	88	0	0%
8	6.0	108	1	1%	89	1	1%

APPENDIX 1C

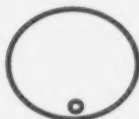
Determination of misalignment errors of the EM34 transmitter and receiver coils

EM34XL Testing - Sensitivity to angle changes in the vertical dipole mode

Testing done May 5/09 @ Avonlea - AREA 1

Controlled Orientation:

Both Tx and Rx red dots facing same direction



Note - both coils at ground level

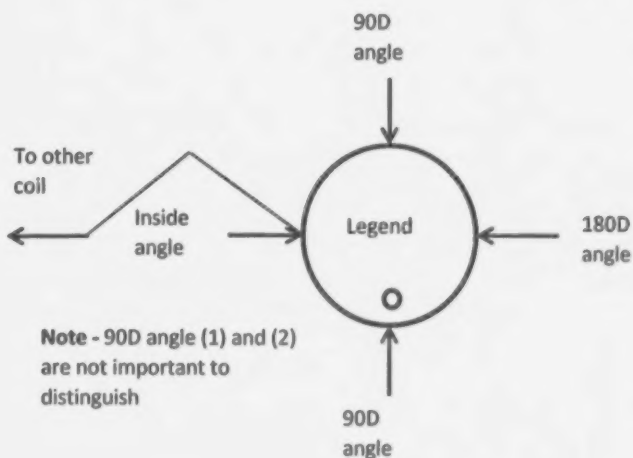
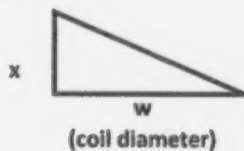
0cm X position is perfectly level

w for Rx coil in cm =

63

w for Tx coil in cm =

100



Note - 90D angle (1) and (2) are not important to distinguish

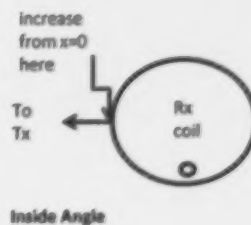
Legend (Other terms)

A1 - Avonlea Area 1

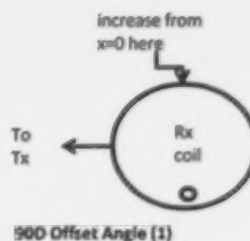
A2 - Avonlea Area 2

ST - Tests w/ steel present - WS (2)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	56	0	0%
2	1.0	0.9	59	3	5%
3	2.0	1.8	63	7	13%
4	3.0	2.7	68	12	21%
5	4.0	3.6	72	16	29%
6	5.0	4.6	76	20	36%
7	6.0	5.5	79	23	41%
8	7.0	6.4	82	26	46%

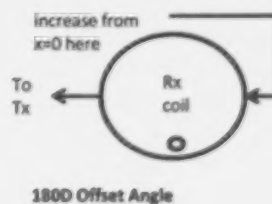


Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	55	0	0%
2	1.0	0.9	54	1	2%
3	2.0	1.8	53	2	4%
4	3.0	2.7	52	3	5%
5	4.0	3.6	51	4	7%
6	5.0	4.6	50	5	9%
7	6.0	5.5	49	6	11%
8	7.0	6.4	48	7	13%

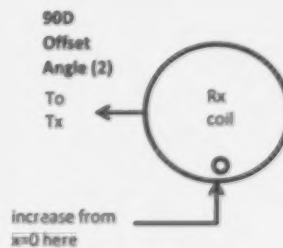


Note: after 7cm measurement the level point changed to 57 mS/m

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	56	0	0%
2	2.0	1.8	49	7	13%
3	4.0	3.6	42	14	25%
4	6.0	5.5	35	21	38%
5	8.0	7.3	28	28	50%
6	11.5	10.5	16	40	71%



Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	56	0	0%
2	0.5	0.5	56	0	0%
3	2.0	1.8	55	1	2%
4	4.0	3.6	55	1	2%
5	6.0	5.5	52	4	7%
6	8.0	7.3	50	6	11%
7	11.5	10.5	45	11	20%

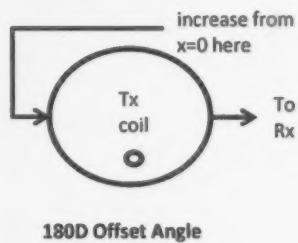
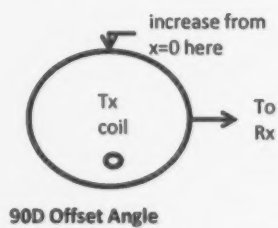
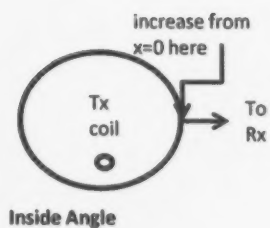


Transmitter (@1000 mS/m sensitivity)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	57	0	0%
2	2.0	1.1	61	4	7%
3	4.0	2.3	67	10	18%
4	6.0	3.4	71	14	25%
5	8.0	4.6	75	18	32%
6	11.5	6.6	83	26	46%

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	57	0	0%
2	2.0	1.1	56	1	2%
3	4.0	2.3	57	0	0%
4	6.0	3.4	57	0	0%
5	8.0	4.6	57	0	0%
6	11.5	6.6	57	0	0%

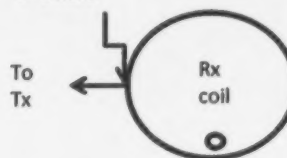
Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	55	0	0%
2	2.0	1.1	52	3	5%
3	4.0	2.3	47	8	15%
4	6.0	3.4	42	13	24%
5	8.0	4.6	38	17	31%
6	11.5	6.6	30	25	45%



Receiver (@1000 mS/m sensitivity)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	53	0	0%
2	2.0	1.8	59	6	11%
3	4.0	3.6	64	11	21%
4	6.0	5.5	70	17	32%
5	8.0	7.3	76	23	43%
6	10.0	9.1	82	29	55%
7	13.5	12.4	91	38	72%

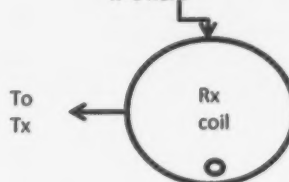
increase from
x=0 here



Inside Angle

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	54	0	0%
2	2.0	1.8	55	1	2%
3	4.0	3.6	55	1	2%
4	6.0	5.5	56	2	4%
5	8.0	7.3	55	1	2%
6	10.0	9.1	54	0	0%
7	13.5	12.4	54	0	0%

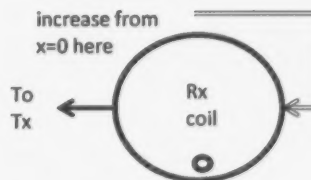
increase from
x=0 here



90D Offset Angle

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	55	0	0%
2	2.0	1.8	49	6	11%
3	4.0	3.6	44	11	20%
4	6.0	5.5	38	17	31%
5	8.0	7.3	32	23	42%
6	10.0	9.1	25	30	55%
6	13.5	12.4	14	41	75%

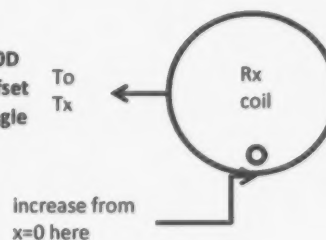
increase from
x=0 here



180D Offset Angle

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	55	0	0%
2	2.0	1.8	55	0	0%
3	4.0	3.6	57	2	4%
4	6.0	5.5	56	1	2%
5	8.0	7.3	55	0	0%
6	10.0	9.1	55	0	0%
7	13.5	12.4	56	1	2%

90D
Offset
Angle

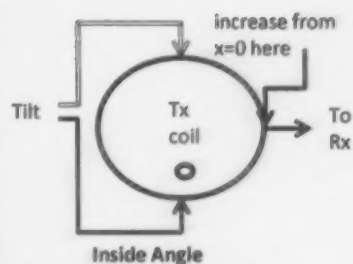


increase from
x=0 here

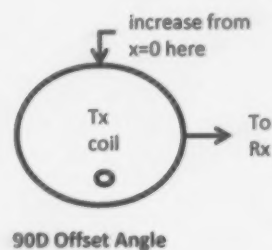
Transmitter (@1000 mS/m sensitivity)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	56	0	0%
2	2.0	1.1	60	4	7%
3	4.0	2.3	64	8	14%
4	6.0	3.4	67	11	20%
5	8.0	4.6	71	15	27%
6	10.0	5.7	74	18	32%
7	13.5	7.8	81	25	45%

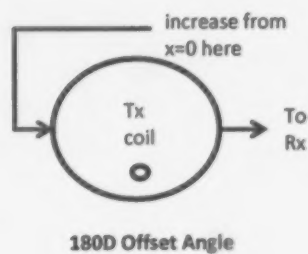
NOTE: When tilting the coil at 13.5 cm, the readings jump all the way down to 68 (from 81)



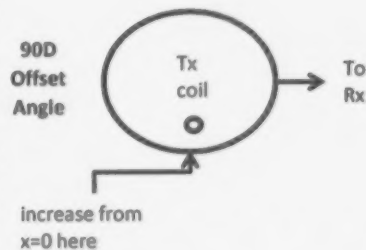
Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	56	0	0%
2	2.0	1.1	57	1	2%
3	4.0	2.3	57	1	2%
4	6.0	3.4	57	1	2%
5	8.0	4.6	57	1	2%
6	10.0	5.7	57	1	2%
7	13.5	7.8	57	1	2%



Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	55	0	0%
2	2.0	1.1	51	4	7%
3	4.0	2.3	47	8	15%
4	6.0	3.4	43	12	22%
5	8.0	4.6	40	15	27%
6	10.0	5.7	36	19	35%
6	13.5	7.8	29	26	47%

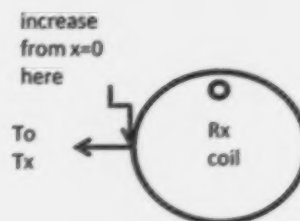


Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	56	0	0%
2	2.0	1.1	55	1	0%
3	4.0	2.3	55	1	0%
4	6.0	3.4	56	0	0%
5	8.0	4.6	56	0	0%
6	10.0	5.7	56	0	0%
7	13.5	7.8	56	0	0%

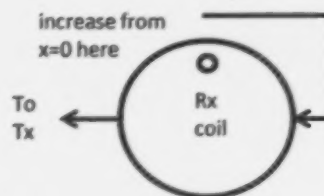


Receiver (@1000 mS/m sensitivity)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	42	0	0%
2	2.0	1.8	45	3	7%
3	4.0	3.6	48	6	14%
4	6.0	5.5	51	9	21%
5	8.0	7.3	55	13	31%
6	10.0	9.1	59	17	40%
7	13.5	12.4	63	21	50%



Inside Angle

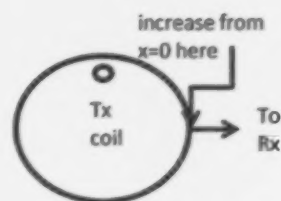


180D Offset Angle

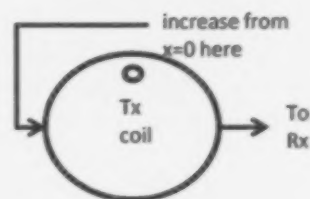
Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	42	0	0%
2	2.0	1.8	39	3	7%
3	4.0	3.6	36	6	14%
4	6.0	5.5	32	10	24%
5	8.0	7.3	29	13	31%
6	10.0	9.1	26	16	38%
6	13.5	12.4	19	23	55%

Transmitter (@1000 mS/m sensitivity)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	42	0	0%
2	2.0	1.1	44	2	5%
3	4.0	2.3	47	5	12%
4	6.0	3.4	49	7	17%
5	8.0	4.6	51	9	21%
6	10.0	5.7	53	11	26%
7	13.5	7.8	56	14	33%



Inside Angle



180D Offset Angle

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	42	0	0%
2	2.0	1.1	41	1	2%
3	4.0	2.3	39	3	7%
4	6.0	3.4	37	5	12%
5	8.0	4.6	35	7	17%
6	10.0	5.7	33	9	21%
6	13.5	7.8	27	15	36%

Testing done Jun 2/09 @ Regina Research Farm Test Site

Receiver (@1000 mS/m sensitivity)

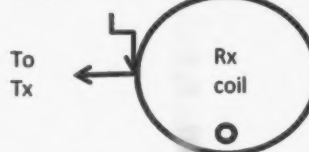
Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	61	0	0%
2	2.0	1.8	66	5	8%
3	4.0	3.6	70	9	15%
4	6.0	5.5	75	14	23%
5	8.0	7.3	80	19	31%
6	10.0	9.1	84	23	38%
7	13.5	12.4	92	31	51%

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	61	0	0%
2	2.0	1.8	56	5	8%
3	4.0	3.6	52	9	15%
4	6.0	5.5	47	14	23%
5	8.0	7.3	42	19	31%
6	10.0	9.1	37	24	39%
6	13.5	12.4	28	33	54%

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	62	0	0%
2	2.0	1.8	62	0	0%
3	4.0	3.6	61	1	2%
4	6.0	5.5	60	2	3%
5	8.0	7.3	60	2	3%
6	10.0	9.1	60	2	3%
7	13.5	12.4	58	4	6%

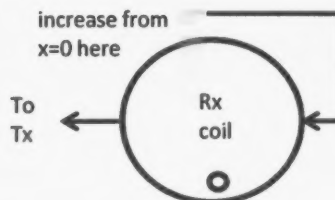
Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	62	0	0%
2	2.0	1.8	62	0	0%
3	4.0	3.6	62	0	0%
4	6.0	5.5	62	0	0%
5	8.0	7.3	61	1	2%
6	10.0	9.1	61	1	2%
7	13.5	12.4	61	1	2%

increase from x=0 here



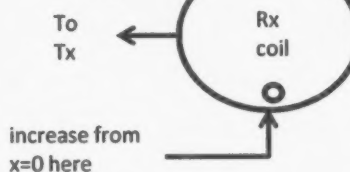
Inside Angle

increase from x=0 here

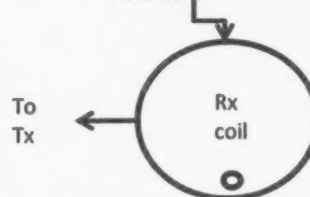


180D Offset Angle

90D Offset Angle



increase from x=0 here



90D Offset Angle

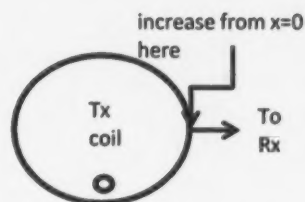
Transmitter (@1000 mS/m sensitivity)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	62	0	0%
2	2.0	1.1	64	2	3%
3	4.0	2.3	67	5	8%
4	6.0	3.4	70	8	13%
5	8.0	4.6	73	11	18%
6	10.0	5.7	76	14	23%
7	13.5	7.8	81	19	31%

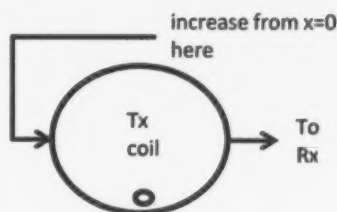
Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	62	0	0%
2	2.0	1.1	58	4	6%
3	4.0	2.3	55	7	11%
4	6.0	3.4	53	9	15%
5	8.0	4.6	50	12	19%
6	10.0	5.7	47	15	24%
6	13.5	7.8	41	21	34%

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	62	0	0%
2	2.0	1.1	62	0	0%
3	4.0	2.3	62	0	0%
4	6.0	3.4	61	1	2%
5	8.0	4.6	61	1	2%
6	10.0	5.7	61	1	2%
7	13.5	7.8	59	3	5%

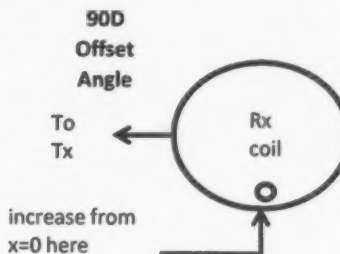
Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	62	0	0%
2	2.0	1.1	63	1	2%
3	4.0	2.3	64	2	3%
4	6.0	3.4	64	2	3%
5	8.0	4.6	64	2	3%
6	10.0	5.7	64	2	3%
7	13.5	7.8	65	3	5%



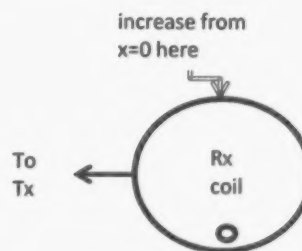
Inside Angle



180D Offset Angle



90D Offset Angle



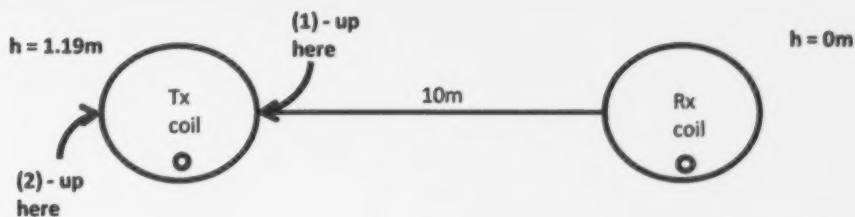
90D Offset Angle

EM34XL Testing - Sensitivity to angle changes in the vertical dipole mode

Testing done May 27/09 @ University of Regina

Angle testing was done with the Tx and Rx coil elevated independently and at the same time
Variable [y] refers to distance from the ground the coil is at

One coil elevated w/ displacement, One coil level on ground

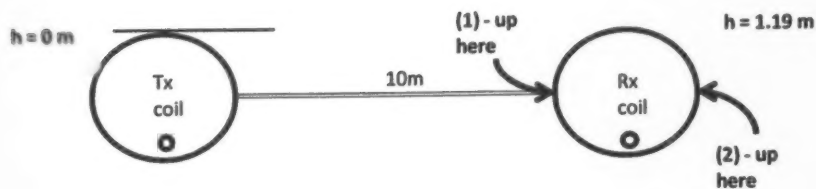


Data Set (1)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	50	0	0%
2	2.0	1.1	52	2	4%
3	4.0	2.3	54	4	8%
4	6.0	3.4	56	6	12%
5	8.0	4.6	58	8	16%
6	10.0	5.7	59	9	18%
7	13.5	7.8	62	12	24%

Data Set (2)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	50	0	0%
2	2.0	1.1	49	1	2%
3	4.0	2.3	47	3	6%
4	6.0	3.4	45	5	10%
5	8.0	4.6	43	7	14%
6	10.0	5.7	41	9	18%
7	13.5	7.8	38	12	24%



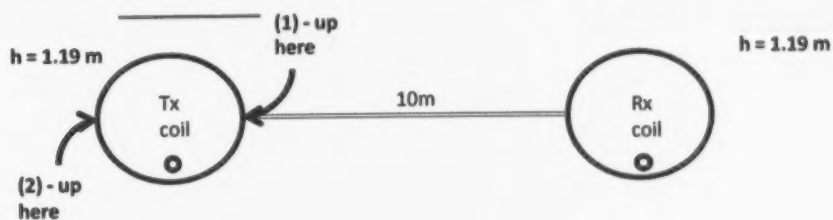
Data Set (1)

Test #	x (cm)	θ (degs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	50	0	0%
2	2.0	1.8	53	3	6%
3	4.0	3.6	56	6	12%
4	6.0	5.5	59	9	18%
5	8.0	7.3	62	12	24%
6	10.0	9.1	65	15	30%
7	13.5	12.4	70	20	40%

Data Set (2)

Test #	x (cm)	θ (degs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	51	0	0%
2	2.0	1.8	48	3	6%
3	4.0	3.6	45	5	10%
4	6.0	5.5	42	8	16%
5	8.0	7.3	39	11	22%
6	10.0	9.1	36	14	27%
7	13.5	12.4	29	21	41%

Both coils elevated w/ single coil displacement

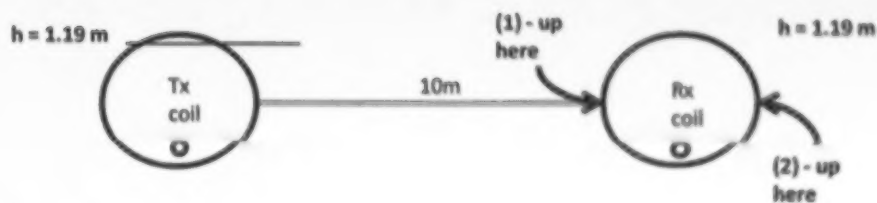


Data Set (1)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	52	0	0%
2	2.0	1.1	54	4	8%
3	4.0	2.3	56	6	12%
4	6.0	3.4	57	7	14%
5	8.0	4.6	59	9	18%
6	10.0	5.7	61	11	22%
7	13.5	7.8	64	14	28%

Data Set (2)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	53	0	0%
2	2.0	1.1	51	1	2%
3	4.0	2.3	50	0	0%
4	6.0	3.4	49	1	2%
5	8.0	4.6	47	3	6%
6	10.0	5.7	46	4	8%
7	13.5	7.8	43	7	14%

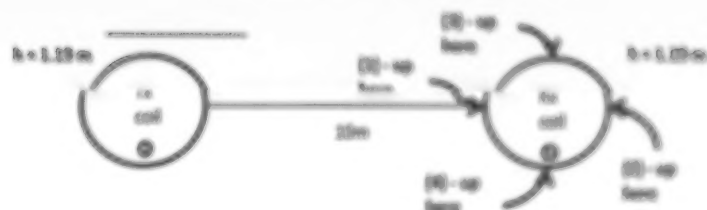


Data Set (1)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	52	0	0%
2	2.0	1.8	54	2	4%
3	4.0	3.6	57	5	10%
4	6.0	5.5	59	7	13%
5	8.0	7.3	62	10	19%
6	10.0	9.1	64	12	23%
7	13.5	12.4	67	15	29%

Data Set (2)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	52	0	0%
2	2.0	1.8	50	2	4%
3	4.0	3.6	46	6	12%
4	6.0	5.5	44	8	15%
5	8.0	7.3	40	12	23%
6	10.0	9.1	38	14	27%
7	13.5	12.4	33	19	37%



Data Set (1)

Test #	x (cm)	θ (deg)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	494	0	0%
2	2.0	3.8	79	4	4%
3	4.0	8.6	76	7	11%
4	6.0	15.1	80	11	14%
5	8.0	22.3	87	16	21%
6	10.0	30.2	87	20	23%
7	12.5	37.4	92	27	29%

Data Set (2)

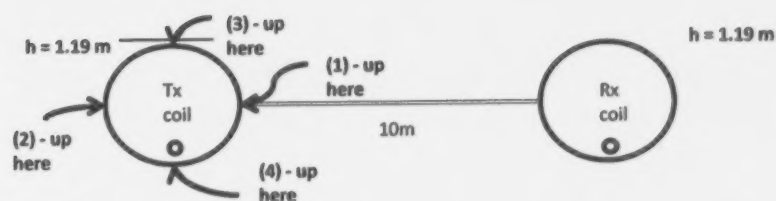
Test #	x (cm)	θ (deg)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	494	0	0%
2	2.0	3.8	65	4	6%
3	4.0	8.6	62	7	11%
4	6.0	15.1	58	11	19%
5	8.0	22.3	54	15	27%
6	10.0	30.2	50	19	38%
7	12.5	37.4	42	27	64%

Data Set (3)

Test #	x (cm)	θ (deg)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	79	0	0%
2	2.0	3.8	79	0	0%
3	4.0	8.6	71	3	4%
4	6.0	15.1	71	3	4%
5	8.0	22.3	79	0	0%
6	10.0	30.2	88	1	1%
7	12.5	37.4	88	1	1%

Data Set (4)

Test #	x (cm)	θ (deg)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	88	0	0%
2	2.0	3.8	79	3	4%
3	4.0	8.6	88	0	0%
4	6.0	15.1	88	0	0%
5	8.0	22.3	88	0	0%
6	10.0	30.2	88	1	1%
7	12.5	37.4	47	2	4%



Data Set (1)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	71	0	0%
2	2.0	1.1	74	3	4%
3	4.0	2.3	76	5	7%
4	6.0	3.4	78	7	10%
5	8.0	4.6	80	9	13%
6	10.0	5.7	83	12	17%
7	13.5	7.8	86	15	21%

Data Set (2)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	72	0	0%
2	2.0	1.1	69	3	4%
3	4.0	2.3	67	5	7%
4	6.0	3.4	64	8	11%
5	8.0	4.6	62	10	14%
6	10.0	5.7	59	13	18%
7	13.5	7.8	55	17	24%

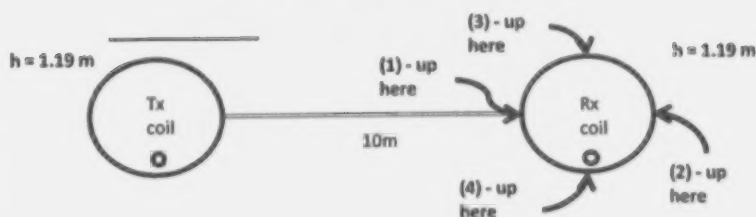
Data Set (3)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	71	0	0%
2	2.0	1.1	71	0	0%
3	4.0	2.3	70	1	1%
4	6.0	3.4	69	2	3%
5	8.0	4.6	68	3	4%
6	10.0	5.7	68	3	4%
7	13.5	7.8	68	3	4%

Data Set (4)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	72	0	0%
2	2.0	1.1	72	0	0%
3	4.0	2.3	72	0	0%
4	6.0	3.4	73	1	1%
5	8.0	4.6	73	1	1%
6	10.0	5.7	73	1	1%
7	13.5	7.8	74	2	3%

Testing done Jun 3/09 @ University of Regina



Data Set (1)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	73	0	0%
2	2.0	1.8	76	3	4%
3	4.0	3.6	79	6	8%
4	6.0	5.5	82	9	12%
5	8.0	7.3	86	13	18%
6	10.0	9.1	89	16	22%
7	13.5	12.4	95	22	30%

Data Set (2)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	73	0	0%
2	2.0	1.8	70	3	4%
3	4.0	3.6	66	7	10%
4	6.0	5.5	62	11	15%
5	8.0	7.3	58	15	21%
6	10.0	9.1	55	18	25%
7	13.5	12.4	48	25	34%

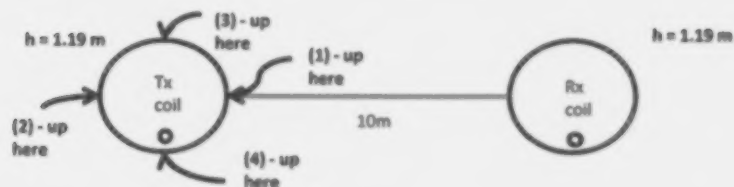
Data Set (3)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	73	0	0%
2	2.0	1.8	72	1	1%
3	4.0	3.6	72	1	1%
4	6.0	5.5	71	2	3%
5	8.0	7.3	71	2	3%
6	10.0	9.1	71	2	3%
7	13.5	12.4	70	3	4%

Data Set (4)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	73	0	0%
2	2.0	1.8	74	1	1%
3	4.0	3.6	74	1	1%
4	6.0	5.5	73	2	3%
5	8.0	7.3	74	2	4%
6	10.0	9.1	74	2	4%
7	13.5	12.4	74	3	4%

5	8.0	7.3	76	3	4%
6	10.0	9.1	76	3	4%
7	13.5	12.4	76	3	4%



Data Set (1)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	72	0	0%
2	2.0	1.1	74	2	3%
3	4.0	2.3	76	4	6%
4	6.0	3.4	79	7	10%
5	8.0	4.6	81	9	13%
6	10.0	5.7	83	11	15%
7	13.5	7.8	87	15	21%

Data Set (2)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	73	0	0%
2	2.0	1.1	71	2	3%
3	4.0	2.3	67	6	8%
4	6.0	3.4	65	8	11%
5	8.0	4.6	63	10	14%
6	10.0	5.7	60	13	18%
7	13.5	7.8	55	18	25%

Data Set (3)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	73	0	0%
2	2.0	1.1	73	0	0%
3	4.0	2.3	73	0	0%
4	6.0	3.4	73	0	0%
5	8.0	4.6	73	0	0%
6	10.0	5.7	73	0	0%
7	13.5	7.8	73	0	0%

Data Set (4)

Test #	x (cm)	θ (degrs)	Cond. mS/m	Abs. error	% error
1	0.0	0.0	73	0	0%
2	2.0	1.1	73	0	0%

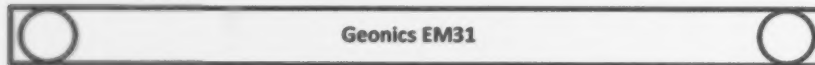
APPENDIX 1D

Effects of aluminum and steel construction materials on EM31 and EM34 readings

EM31 Testing - Sensitivity to angle changes of metal rods in the vertical dipole mode Testing done May 20/09 @ Avonlea - AREA 2

Steel used:	3 ft of 3/4" square tubing	Aluminum	used:	3 ft of 3/4" square tubing
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Measurements made at 0 elevation



Base reading: 112 mS/m

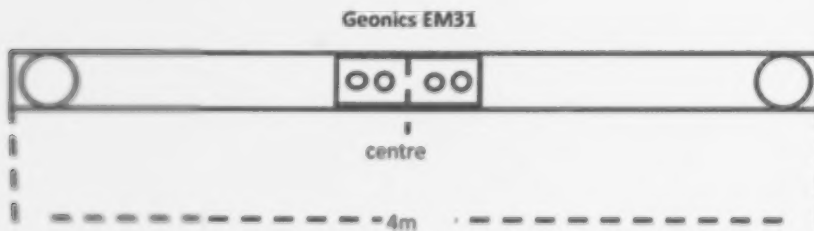
w/ steel present	@ transmitter:	120 mS/m
	@ receiver:	120 mS/m

w/ aluminum present	@ transmitter:	110 mS/m
	@ receiver:	115 mS/m

EM31 Testing - Sensitivity to aluminum Testing done Aug. 11/09 @ UofR

Steel used:	3 ft of 3/4" square tubing	Aluminum	used:	3 ft of 3/4" square tubing
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Measurements made at 0 elevation



Estimated capsule length of 30 cm (confirm later)

Base reading (instruments off no conductive interference):

128.6 mS/m

AI distance (x) from Transmitter End (aluminum pieces laid perpendicular to 31 length)

Test #	x (cm)	Cond. Change mS/m		% error	Note	Picture # (DSC050##)
1	175.0	0.1		0.1%	10cm from middle console	13
2	155.0	0.1		0.1%	30cm from middle console	14
3	135.0	0.2		0.2%	50cm from middle console	15
4	75.0	0.3		0.2%	1m from middle console	17
5	50.0	0.3		0.2%	1.2m from console	18

Note: @40cm from the transmitter end the numbers begin to become unstable

AI distance (x) from Transmitter End (aluminum pieces laid parallel to 31 length)

Test #	x (cm)	Cond. Change mS/m		% error	Note	Picture # (DSC050##)
1	94.0	0.3		0.2%	one end touching console other end extending towards transmitter	16

AI distance (x) from Receiver End (aluminum pieces laid perpendicular to 31 length)

Test #	x (cm)	Cond. Change mS/m		% error	Note	Picture # (DSC050##)
1	25.0	3.0		2.3%	/	19
2	115.0	0.0		0.0%	70cm from middle console	20

AI distance (x) from Transmitter End (aluminum pieces laid parallel to 31 length)

Test #	x (cm)	Cond. Change mS/m		% error	Note	Picture # (DSC050##)
1	94.0	0.0		0.0%	one end touching console other end extending towards transmitter	21
2	50.0	0.0		0.0%		22

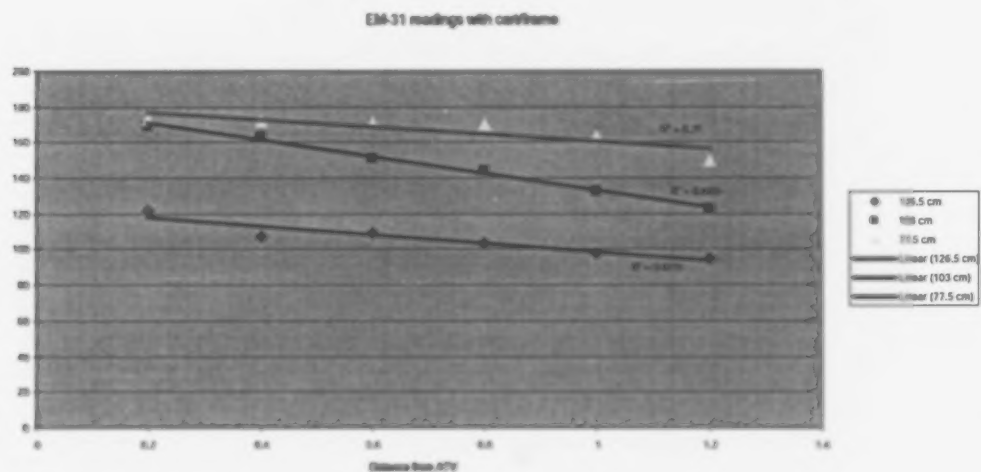
EM34XL Testing - Sensitivity to metal tubing in the vertical dipole mode
Testing done May 20/09 @ Avonlea - AREA 2

Steel	3 ft of 3/4" square	Aluminum	3 ft of 3/4" square
used:	tubing	used:	tubing

Measurements made at 0 elevation

	mS/m Before	mS/m After
When steel (2 pcs) was placed in the centre of receiver coil:	56	60
When alum. (2 pcs) was placed in the centre of receiver coil:	56	56

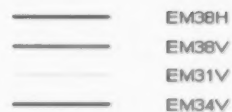
EM31 Testing - Sensitivity to metal in the ATV and in the precision frame



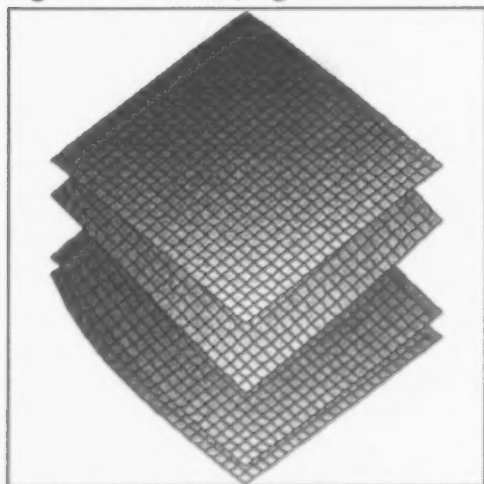
APPENDIX 2A

Two-Layer Case, Fixed layer conductivity, varying instrument height

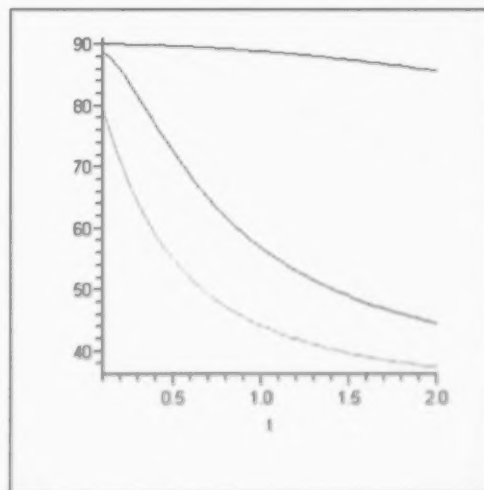
The legend for each of the graphs is shown on the right.



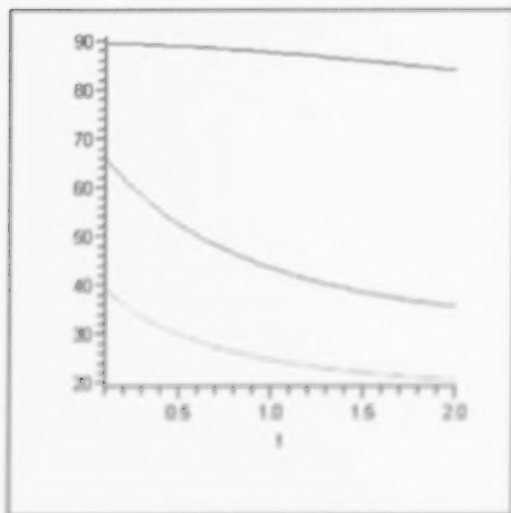
$\Sigma_1 = 60 \text{ mS/m}$, $\Sigma_2 = 90 \text{ mS/m}$



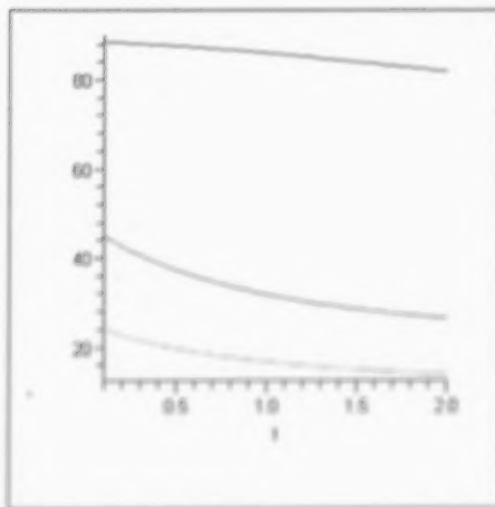
Full Range of variation



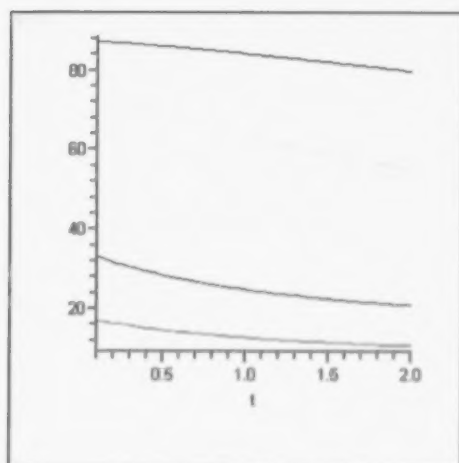
Height = 0



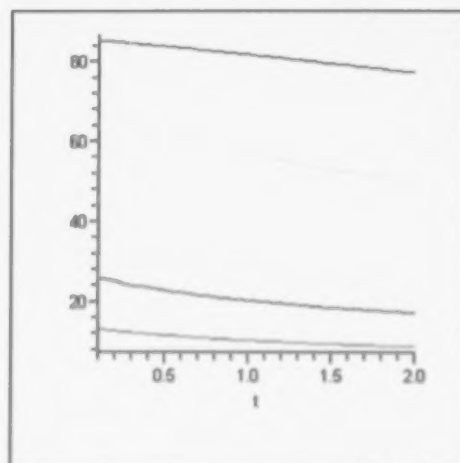
Height = 0.4m



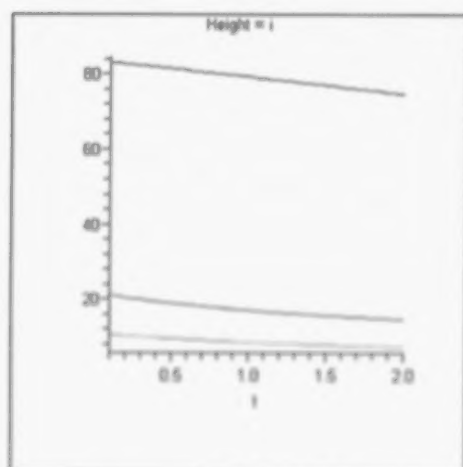
Height = 0.8m



Height = 1.2m

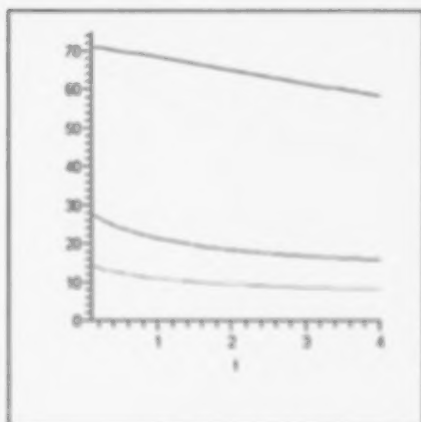


Height = 1.6m

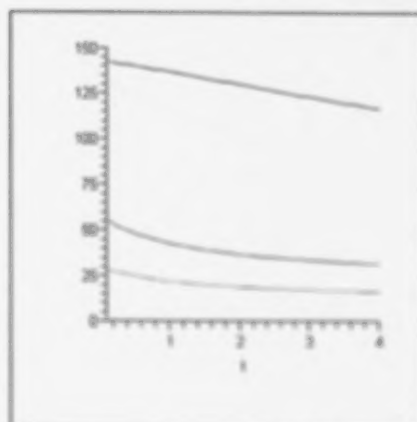


Height = 2.0m

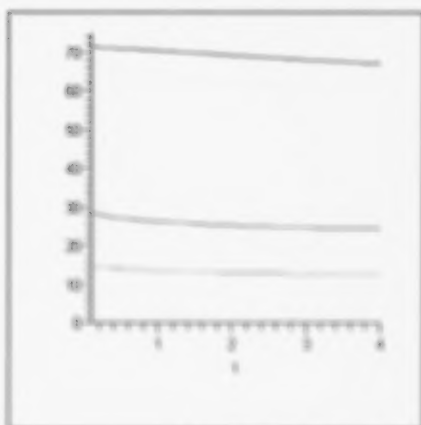
2-Layer Case, Fixed height, comparing conductivity ranges varying T1



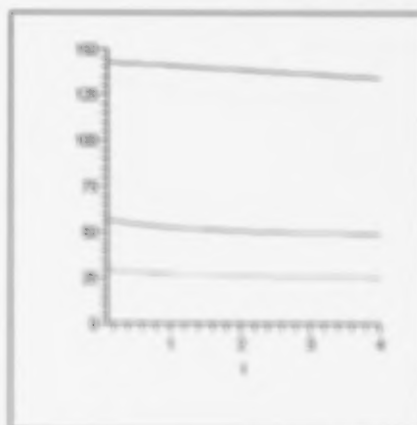
sigma1 = 30, sigma2 = 75



sigma1 = 60, sigma2 = 150



sigma1 = 60, sigma2 = 75

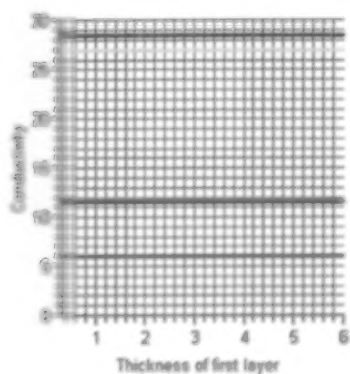


sigma1 = 120, sigma2 = 150

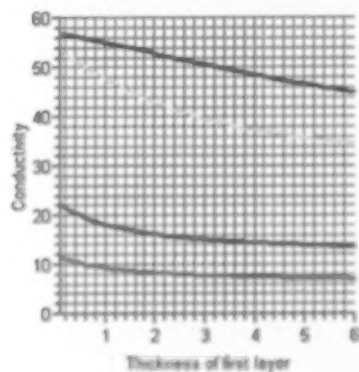
These curves are fixed at given ratios of sigma 1 to sigma 2.

2-Layer Case, Fixed Height, identifying conductivity ratios

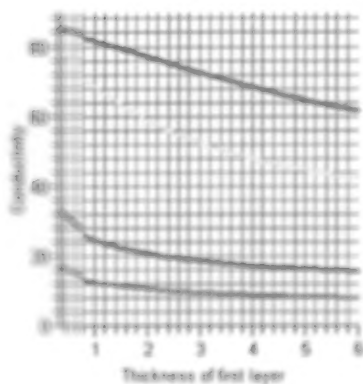
1.1 Actual Conductivity vs Thickness; 30,30



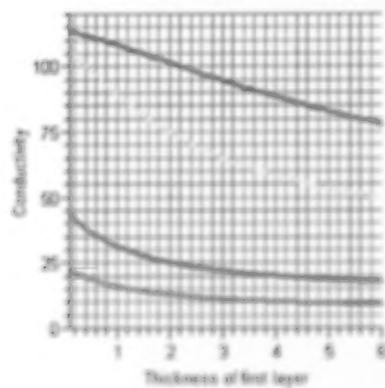
1.2 Actual Conductivity vs Thickness; 30,60



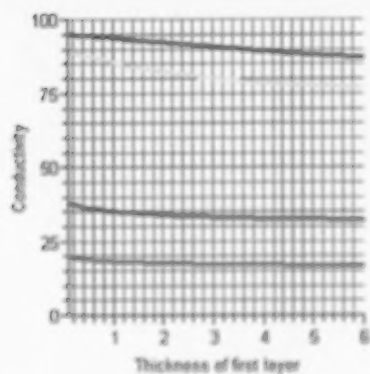
1.3 Actual Conductivity vs Thickness; 30,90



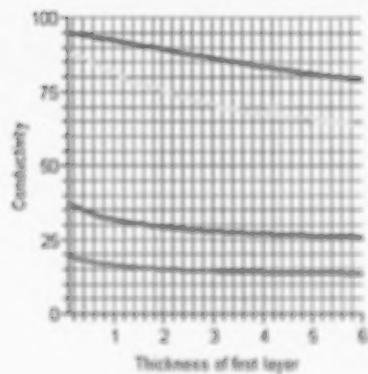
1.4 Actual Conductivity vs Thickness; 30,120



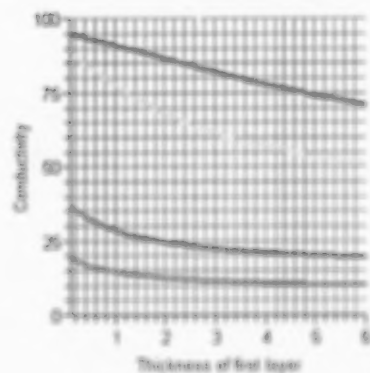
4.5 Actual Conductivity vs Thickness; 60,100



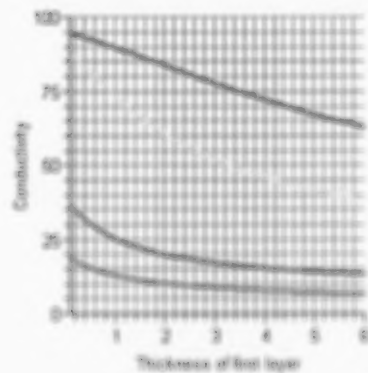
3.5 Actual Conductivity vs Thickness; 60,100



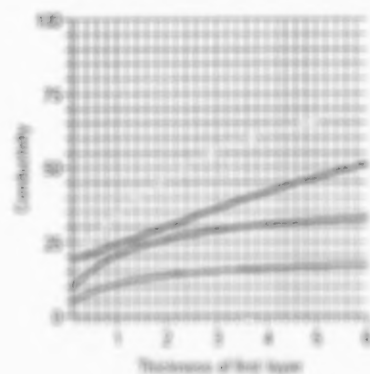
2.5 Actual Conductivity vs Thickness; 40,100



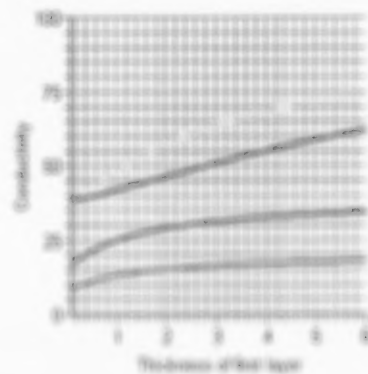
1.5 Actual Conductivity vs Thickness; 20,100



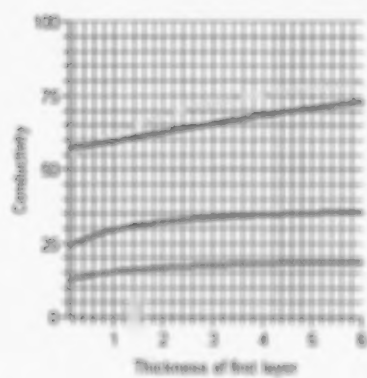
5.1 Actual Conductivity vs Thickness; 100,20



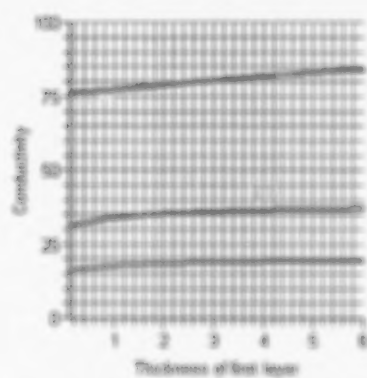
5.2 Actual Conductivity vs Thickness; 100,40



5.3 Actual Conductivity vs Thickness, 100.00



5.4 Actual Conductivity vs Thickness, 100.00

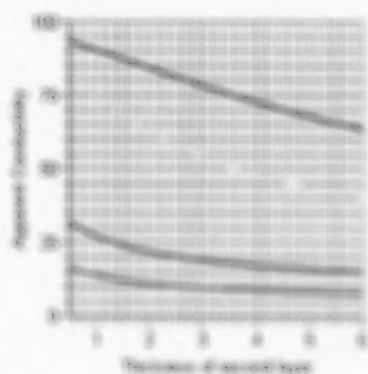


3-Layer Case, Fixed conductivities, fixed top layer, plot by intermediate thickness

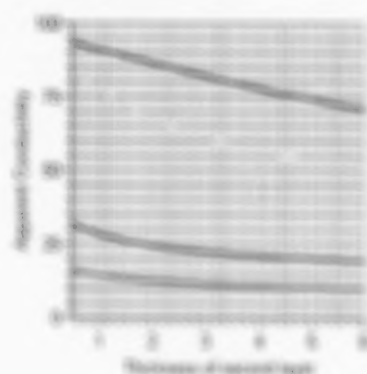
This series investigates the same curves as the previous set, but we're interested in what it looks like when there is a layer of fixed thickness (top-soil) above the level of varying thickness. This displays what we might see when varying the density of an aquifer layer that sits on top of a clay bed. The fixed top layer is of thickness 0.5m and so in the case where $\sigma_{top} = \sigma_{mid}$ then there is a slight offset from previous graphs amounting for the fact that the bottom layer's minimum start point is at $z=0.5m$ as opposed to $z=0.2m$.

Dry Topsoil Layer

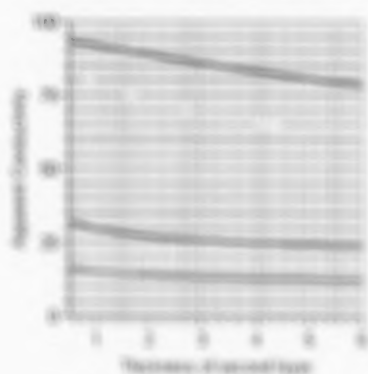
2.1.2 Actual Conductivity vs Thickness, 40, 20, 100



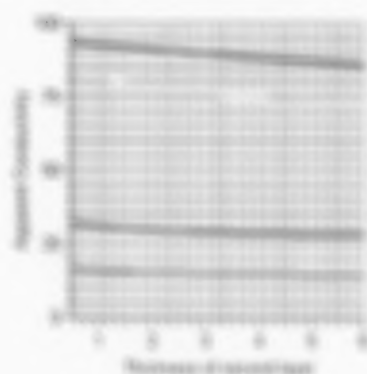
2.1.3 Actual Conductivity vs Thickness, 40, 20, 100



2.1.4 Actual Conductivity vs Thickness, 40, 20, 100

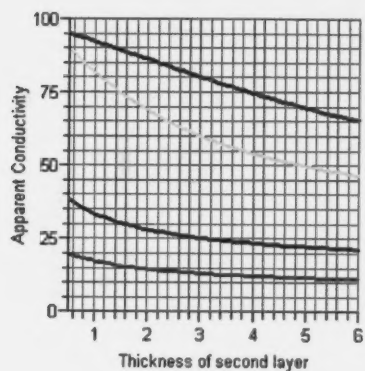


2.1.5 Actual Conductivity vs Thickness, 40, 20, 100

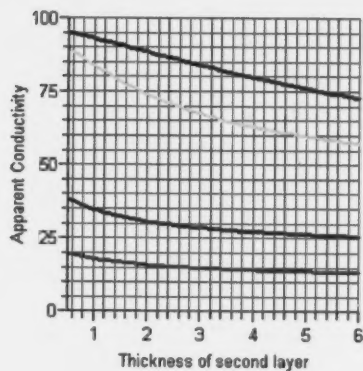


Saturated Topsoil Layer

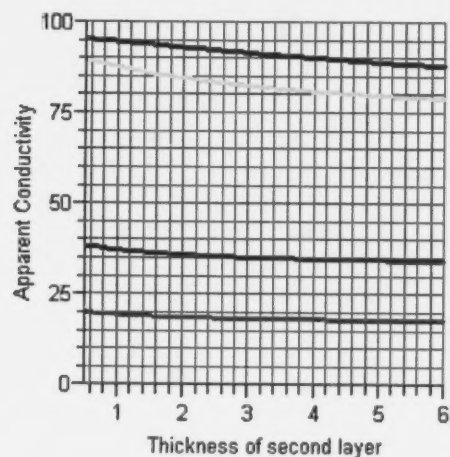
5:1:5 Actual Conductivity vs Thickness; 100,20,100



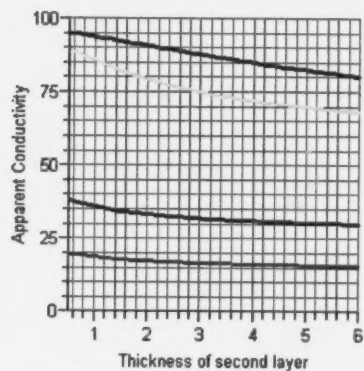
5:2:5 Actual Conductivity vs Thickness; 100,40,100



5:4:5 Actual Conductivity vs Thickness; 100,80,100

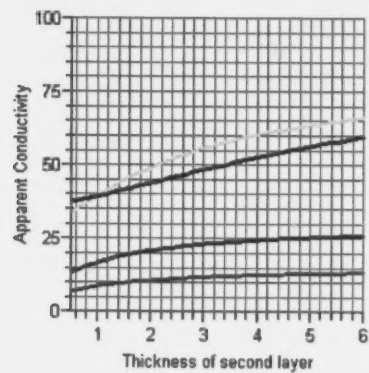


5:3:5 Actual Conductivity vs Thickness; 100,60,100

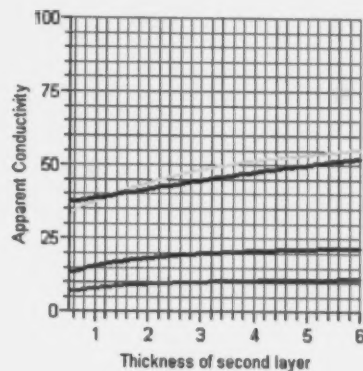


Dry Topsoil above shallow aquifer with clay barrier

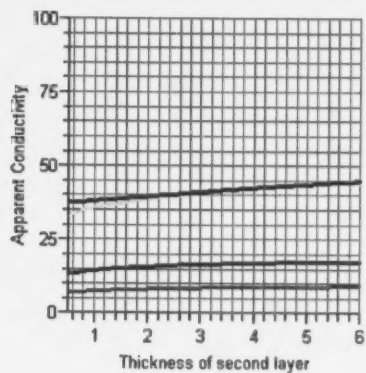
1:5:2 Actual Conductivity vs Thickness; 20,100,40



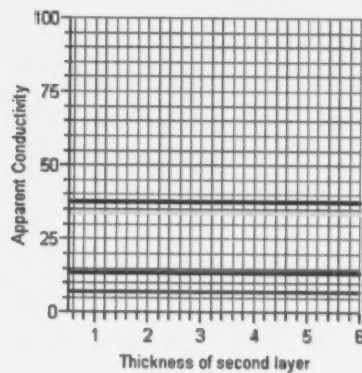
1:4:2 Actual Conductivity vs Thickness; 20,80,40



1:3:2 Actual Conductivity vs Thickness; 20,60,40

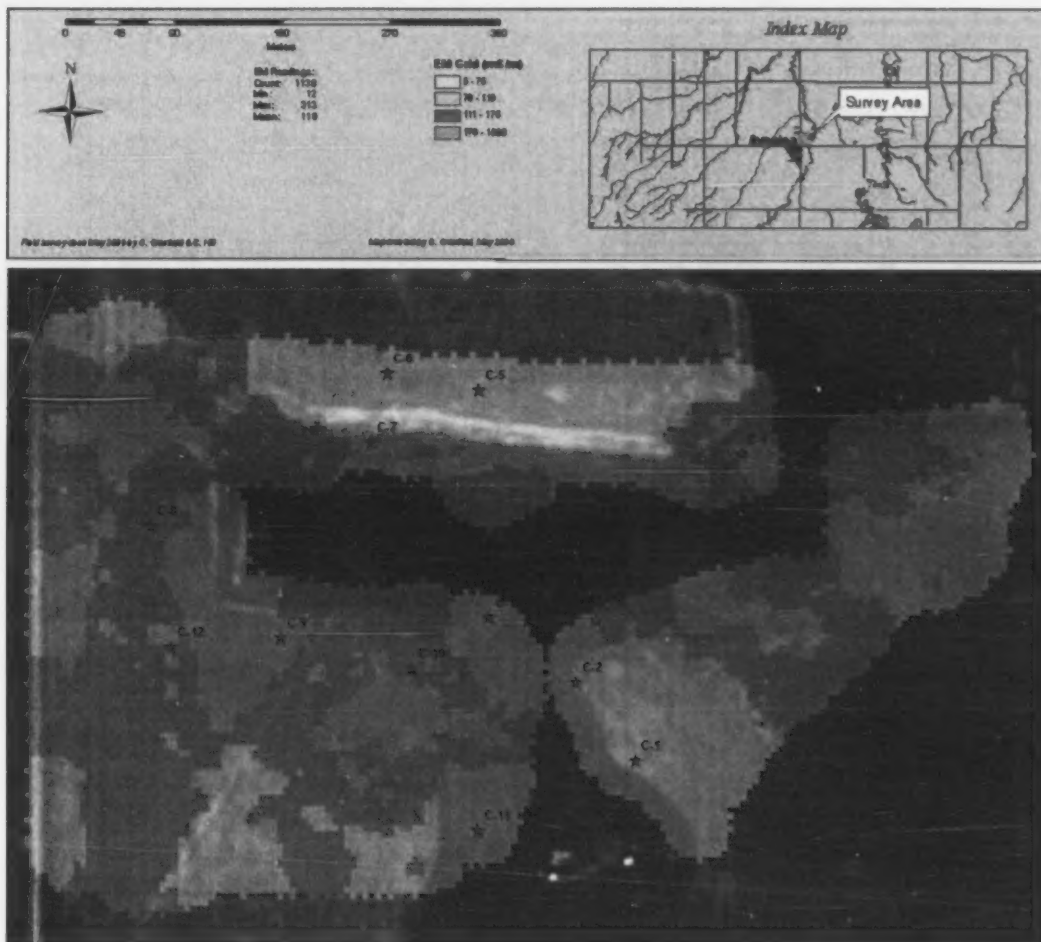


1:2:2 Actual Conductivity vs Thickness; 20,40,40

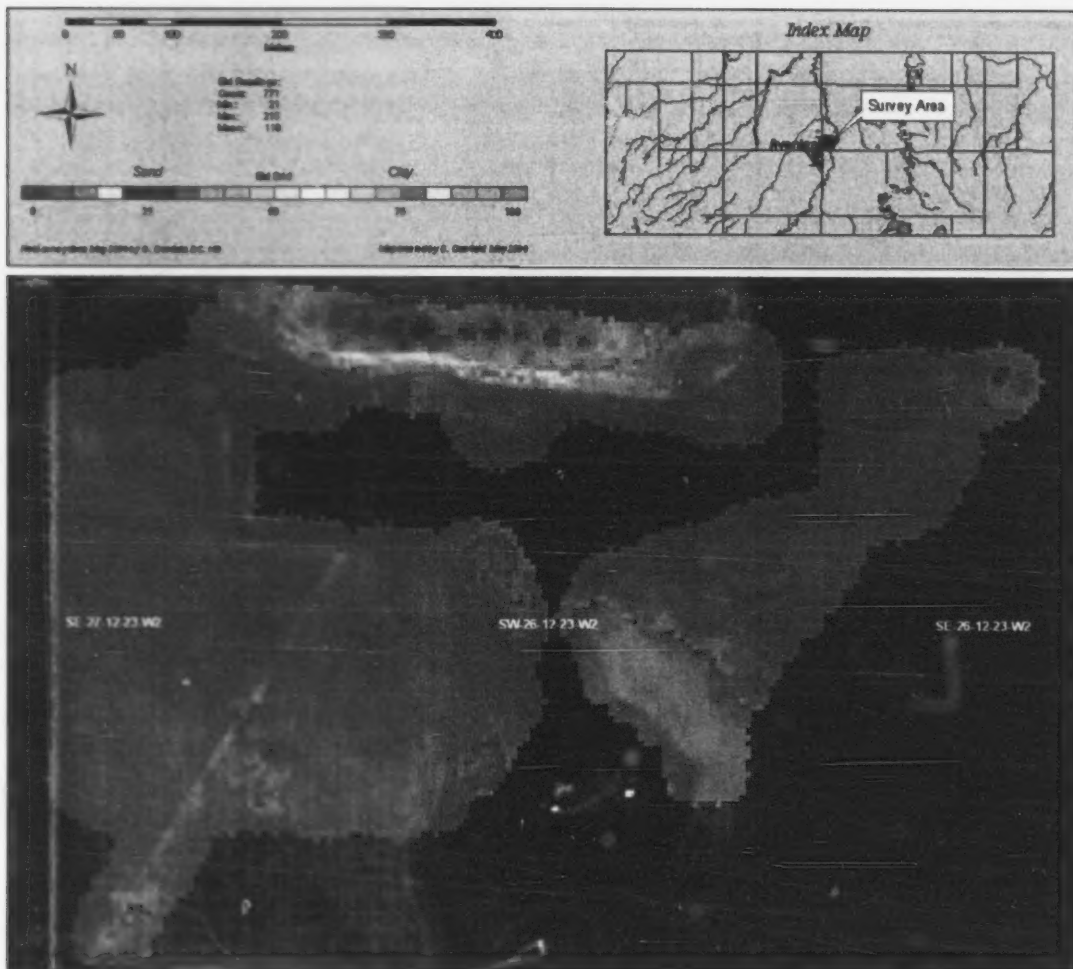


APPENDIX 3A **Conductivity readings and soil core lab results** **Avonlea**

Avonlea wetlands – EM38 electromagnetic contour map and locations of drill holes



Avonlea wetlands – EM31 electromagnetic contour map



EM38DD/EM31 Testing - Changes in operating height in the vertical/horizontal dipole modes

Testing done July 5/2009 @ Avonlea, Sask. -- Done by: Chris H, Evan M, Sean S, Alex C

**Drill
Location : C6**

**Plastic
Frame**

**GPS Eastings: 13
Loc: 496351
Northings:
5541215**

EM31

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0	48	37
1	26	46	34
2	52	42	29
3	77.5	38	24
4	103	35	21
5	126.5	32	18
6	152.5	29	16

EM38

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0	26	-6
1	26	20	-11
2	52	16	-16
3	77.5	13	-19
4	103	10	-22
5	126.5	7	-23
6	152.5	7	-23

**Drill
Location : C7**

**Plastic
Frame**

**GPS Eastings: 13
Loc: 496338
Northings:
5541160**

EM31

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0	95	98
1	26	97	86
2	52	93	73
3	77.5	87	62
4	103	81	53
5	126.5	74	46.5
6	152.5	67	40.5

EM38

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0		
1	26		
2	52		
3	77.5		
4	103		
5	126.5		
6	152.5		

Drill
Location : C9

Plastic
Frame

GPS Eastings: 13
Loc: 496265
Northings:
5541003

EM31

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0	196	268
1	26	199	235
2	52	198	198
3	77.5	190	166
4	103	179	140
5	126.5	167	121
6	152.5	151	103

EM38

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0	260	245
1	26	200	131
2	52	146	75
3	77.5	108	43
4	103	82	24
5	126.5	66	13
6	152.5	54	4

Drill
Location : C10

Wooden
Frame

GPS Eastings: 13
Loc: 496371
Northings:
5540979

EM31

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0	160	224
1	16	170	209
2	31.5	171	185
3	46.5	170	165.5
4	61.5	166	149
5	76.5	161.5	134.5
6	91.5	155	121
7	106.5	148	111
8	121	141	101
9	136.5	134	92
10	151	126	84

EM38

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0	210	166
1	16	175	110
2	31.5	143	77
3	46.5	119	58
4	61.5	99	40
5	76.5	83	27
6	91.5	71	18
7	106.5	61	11
8	121	53	6
9	136.5	47	2
10	151	41	-1

Drill

Location :

C11

Plastic

Frame

GPS

Loc:

Eastings: 13

496433

Northings:

5541020

EM31

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0	77.5	72
1	26	79	65
2	52	74	54.5
3	77.5	69	46.5
4	103	63.5	40
5	126.5	58	36
6	152.5	53	31

EM38

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0	58	30
1	26	46	11
2	52	34	-1
3	77.5	26	-10
4	103	21	-16
5	126.5	16	-17
6	152.5	15	-19

Drill

Location :

C12

Wooden

Frame

GPS

Loc:

Eastings: 13

496176

Northings:

5540996

EM31

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0	206	147
1	16	200	139
2	31.5	190	120
3	46.5	179	111
4	61.5	167	101
5	76.5	157	93
6	91.5	147	85
7	106.5	138	79
8	121	128	72
9	136.5	120	66
10	151	112	61.5

EM38

Level	Height (cm)	VD (mS/m)	HD (mS/m)
Ground	0	96	34
1	16	82	25
2	31.5	72	17
3	46.5	63	11
4	61.5	56	6
5	76.5	50	2
6	91.5	45	-3
7	106.5	39	-5
8	121	35	-6
9	136.5	32	-9
10	151	28	-10

1

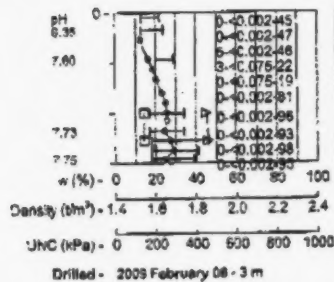
MAXWELL LAB

PAGE 02



C 6

EL m



- TILL (CL), very stiff
- SM, fine, pkts clay
- CL, stiff, lenses ML, pkts CaCO₃, slightly sandy
- seam sand
- CL, stiff, lenses ML
- seams ML, fractures oxidized
- seams ML, fractures oxidized, pkts CH
- seams ML, fractures oxidized, pkts CH & gypsum
- seams ML, fractures oxidized

WL - June 2, 2009 - Dry
GPS: UTM 13, 496351 E, 5541215 N

Agriculture and Agri-Food Canada Ministère de l'Agriculture et des Pêcheries Canada	Avonlea Constructed Wetlands SW 26-12-23 W2		
	Drawn/Checked: NB/CH	2009/07/06	1585-1-18-2

LABORATORY TEST RESULTS

Hole No. 57
 Classified by GP
 Date 10/10/68

Atterberg Limits

W_L - Liquid limit
 W_P - Plastic limit
 I_P - Plasticity index

Granular

D₁₀, D₃₀, D₆₀ - Percent by wt. finer than given dia.
 C_u - Coefficient of uniformity
 C_c - Coefficient of curvature

All grain sizes are listed as percent by wt

pH - Hydrogen ion concentration
 S₀₄ - Water soluble sulphates in soil
 cc - Clay content <0.002 mm
 SG - Specific gravity
 U - Unconfined compressive strength
 PP - Pocket penetrometer
 spt - Suitability for physical tests
 H - Hydrometer test

Sample No.	Lab. Classification		Water Content %	Wet Density t/m ³	W _L	D ₁₀	D ₃₀	Cobbles	Coarse Sand	Fines <0.075 mm	pH	U	PF
Depth m	Group	Description			W _P	D ₁₀	C _c	Coarse Gravel	Med. Sand	cc	SG	kPa at w%	kP
0.1	1A	black sandy clay											
0.3	1A												
0.5	1B	very silty clay	20.3										
0.5	1B	greyish brown silty clay											
0.5	1A	GS above	24.1										
0.5	1B												
1.5	2A	fine silty clay	12.1										
2.0	2A	fine silty clay											
2.5	2A	fine silty clay	12.1										
3.0	2A	fine silty clay											
3.5	2A	fine silty clay	12.1										
4.0	2A	fine silty clay											
4.5	2A	fine silty clay	12.1										
5.0	2A	fine silty clay											
5.5	2A	fine silty clay	12.1										
6.0	2A	fine silty clay											
6.5	2A	fine silty clay	12.1										
7.0	2A	fine silty clay											
7.5	2A	fine silty clay	12.1										
8.0	2A	fine silty clay											
8.5	2A	fine silty clay	12.1										
9.0	2A	fine silty clay											
9.5	2A	fine silty clay	12.1										
10.0	2A	fine silty clay											

PF2073 479

LABORATORY TEST RESULTS

Hole No.	67
Classified by	GRL
Date	June 11, 1961

Atterberg Limits

w_L - Liquid limit
 w_p - Plastic limit
 I_p - Plasticity index

Granular

D_{10}, D_{30}, D_{60} - Percent by wt. finer than given dia.
 C_u - Coefficient of uniformity
 C_c - Coefficient of curvature

All grain sizes are listed as percent by wt.

pH - Hydrogen ion concentration
 SO_4 - Water soluble sulphates in soil
 cc - Clay content <0.002 mm
 SG - Specific gravity
 U - Unconfined compressive strength
 PP - Pocket penetrometer
 spt - Suitable for physical tests
 H - Hydrometer test

Sample No.	Lab Classification	Water Content %	Wet Density γ/m^3	w_L	D_{10}	D_{30}	Cobbles	Coarse Sand	Fines <0.075 mm	pH	U	PP
Depth m	Group	Description		I_p	C_u	C_c	Coarse Gravel	Med. Sand	cc	SG	γ_{Pa}	γ_{Pa}
1.5	3	top 6" dark gray	16.4									
2.15	3	very sandy										
		large rocks										
2.25	4	dark gray, brown, large	16.1									
2.35		1' sand & silt										
		15% fines										
2.45	5	light gray	25.1									
2.55												
2.65	5	light gray	25.1									
2.75												
2.85	5	light gray	25.5									
2.95		light gray & brown silt										

PF2073 479

Hole No.	2
Classified by	<i>[Signature]</i>
Date	<i>[Signature]</i>

w_L - Liquid limit
 w_p - Plastic limit
 I_p - Plasticity index

D_{10}, D_{30}, D_{50} - Percent by wt. finer than given dia.
 C_u - Coefficient of uniformity
 C_c - Coefficient of curvature

pH - Hydrogen ion concentration
 SQ_s - Water soluble sulphates in soil
 cc - Clay content <0.002 mm
 SG - Specific gravity
 U - Unconfined compressive strength
 PP - Pocket penetrometer
 spt - Suitable for physical tests
 H - Hydrometer test

[illegible]

105

LABORATORY TEST RESULTS

Hole No. 10
 Classified by LR/RP
 Date June 18/68

Atterberg Limits

WL - Liquid limit
 WP - Plastic limit
 IP - Plasticity index

Granular

D₁₀, D₃₀, D₆₀ - Percent by wt finer than given dia.
 C_u - Coefficient of uniformity
 C_c - Coefficient of curvature

All grain sizes are listed as percent by wt

pH - Hydrogen ion concentration
 S₀₄ - Water soluble sulphates in soil
 cc - Clay content <0.002 mm
 SG - Specific gravity
 U - Unconfined compressive strength
 PP - Pocket penetrometer
 spt - Suitable for physical tests
 H - Hydrometer test

Sample No.	Lab. Classification		Water Content %	Wet Density t/m ³	WL	D ₁₀	D ₃₀	Cobbles	Coarse Sand	Fines <0.075 mm	pH S ₀₄	U	PF
Depth m	Group	Description			WP	D ₁₀	D ₃₀	Coarse Gravel	Med. Sand	cc	SG	xPa at w%	kP
1.5	SP	Light grey silty clay with some sand	35.1	1.87									115
1.7	SP	Light grey silty clay with some sand											
1.8	SP	Light grey silty clay with some sand											
2.0	SP	Light grey silty clay with some sand	32.0										
2.2	SP	Light grey silty clay with some sand											
2.4	SP	Light grey silty clay with some sand											
2.6	SP	Light grey silty clay with some sand	31.0	1.85									115
2.8	SP	Light grey silty clay with some sand											
3.0	SP	Light grey silty clay with some sand	32.0										
3.2	SP	Light grey silty clay with some sand											
3.4	SP	Light grey silty clay with some sand											
3.6	SP	Light grey silty clay with some sand	27.1	1.85									90
3.8	SP	Light grey silty clay with some sand											
4.0	SP	Light grey silty clay with some sand											
4.2	SP	Light grey silty clay with some sand	27.4										5
4.4	SP	Light grey silty clay with some sand											
4.6	SP	Light grey silty clay with some sand											
4.8	SP	Light grey silty clay with some sand	26.9										
5.0	SP	Light grey silty clay with some sand											
5.2	SP	Light grey silty clay with some sand											
5.4	SP	Light grey silty clay with some sand	27.8										
5.6	SP	Light grey silty clay with some sand											
5.8	SP	Light grey silty clay with some sand											

PF2073 479

APPENDIX 3B **Conductivity readings and soil core lab results** **Indian Head Research Farm**

Indian Head Research Farm – lab results: Field 1436

YEAR	PLOT	BLOC	MP	SP	Crop	Nrate	0-12" %	12-24" %	24-36" %	0-12" cm	12-24" cm	24-36" cm
2009	1	1	2	3	Fababean	50 N 100	35.3	21.4	20.2	11.8	8.2	7.5
2009	2	1	2	5	Fababean	N	34.0	20.3	17.4	12.6	7.6	8.2
2009	3	1	2	4	Fababean	75 N	32.9	21.2	19.1	10.2	8.4	7.8
2009	4	1	2	2	Fababean	25 N	32.4	25.8	22.2	9.3	10.8	8.8
2009	5	1	2	1	Fababean	0 N	29.2	19.7	22.5	11.6	7.8	8.3
2009	6	1	3	3	FababeanGM	50 N 100	36.2	29.1	26.9	11.0	12.3	10.1
2009	7	1	3	5	FababeanGM	N	36.2	28.3	23.9	15.5	11.7	13.8
2009	8	1	3	1	FababeanGM	0 N	39.3	33.2	26.8	11.4	13.1	11.3
2009	9	1	3	4	FababeanGM	75 N	30.5	27.1	28.3	12.2	11.2	14.3
2009	10	1	3	2	FababeanGM	25 N	32.7	28.5	26.4	12.4	10.9	10.7
2009	11	1	4	2	Lentil (CF)	25 N	34.5	26.7	22.7	11.0	10.5	8.9
2009	12	1	4	1	Lentil (CF)	0 N	34.7	26.7	23.7	11.9	12.1	12.4
2009	13	1	4	4	Lentil (CF)	75 N	35.6	27.4	24.9	12.4	12.3	9.9
2009	14	1	4	3	Lentil (CF)	50 N 100	35.8	27.5	22.0	13.1	11.2	7.3
2009	15	1	4	5	Lentil (CF)	N	34.5	27.0	21.5	11.9	10.7	8.8
2009	16	1	1	4	Field Pea	75 N	37.7	32.0	23.7	12.7	11.7	7.4
2009	17	1	1	1	Field Pea	0 N	37.9	31.4	21.7	13.2	11.2	10.5
2009	18	1	1	2	Field Pea	25 N	33.7	28.9	22.2	14.7	8.6	10.2
2009	19	1	1	3	Field Pea	50 N 100	34.0	27.1	20.3	11.9	11.6	9.6
2009	20	1	1	5	Field Pea	N	35.1	27.3	18.3	12.5	10.2	8.2
2009	21	1	5	2	Canola (CF)	25 N	36.4	25.1	21.6	11.1	8.5	8.6
2009	22	1	5	3	Canola (CF)	50 N	34.4	20.0	21.5	10.7	7.8	5.9
2009	23	1	5	1	Canola (CF)	0 N 100	33.3	25.5	21.0	11.6	9.7	10.9
2009	24	1	5	5	Canola (CF)	N	34.9	27.3	23.6	12.3	10.1	9.4
2009	25	1	5	4	Canola (CF)	75 N 100	33.2	23.6	19.9	12.5	9.8	9.2
2009	26	1	6	5	Wheat (CF)	N	32.9	27.0	20.8	12.1	11.9	8.0
2009	27	1	6	2	Wheat (CF)	25 N	35.6	28.1	20.5	12.1	10.5	10.2
2009	28	1	6	4	Wheat (CF)	75 N	34.5	28.7	20.6	13.1	11.0	8.1
2009	29	1	6	3	Wheat (CF)	50 N	35.7	25.2	21.6	13.4	9.6	9.0
2009	30	1	6	1	Wheat (CF)	0 N	38.1	25.8	20.5	13.2	9.6	6.7
2009	31	2	4	3	Lentil (CF)	50 N 100	36.1	30.4	27.7	15.1	10.2	7.1
2009	32	2	4	5	Lentil (CF)	N	34.0	26.2	23.0	10.9	11.0	9.6
2009	33	2	4	1	Lentil (CF)	0 N	32.7	27.3	25.3	11.6	10.4	8.7
2009	34	2	4	2	Lentil (CF)	25 N	31.4	27.6	22.6	12.0	10.2	9.3
2009	35	2	4	4	Lentil (CF)	75 N	33.3	25.5	23.8	12.1	10.2	9.4
2009	36	2	2	4	Fababean	75 N	32.2	23.7	20.7	11.5	8.6	9.1
2009	37	2	2	3	Fababean	50 N	31.6	22.1	16.8	11.3	8.4	10.6

YEAR	PLOT	BLOC	MP	SP	Crop	Nrate	0-12" %	12- 24" %	24- 36" %	0- 12" cm	12- 24" cm	24- 36" cm
2009	38	2	2	5	Fababean	N	32.6	21.7	16.0	11.5	7.8	9.0
2009	39	2	2	2	Fababean	25 N	31.8	20.0	18.4	13.1	7.8	8.5
2009	40	2	2	1	Fababean	0 N	32.8	22.4	21.9	11.7	8.7	9.3
2009	41	2	3	3	FababeanGM	50 N	35.4	27.9	19.5	13.0	13.8	11.9
2009	42	2	3	2	FababeanGM	25 N	34.9	28.9	26.3	13.6	13.0	11.5
						100						
2009	43	2	3	5	FababeanGM	N	33.8	29.1	27.8	14.2	10.7	6.2
2009	44	2	3	1	FababeanGM	0 N	34.9	28.2	26.6	12.0	13.2	14.6
2009	45	2	3	4	FababeanGM	75 N	37.4	32.7	25.5	10.6	12.4	13.3
2009	46	2	6	1	Wheat (CF)	0 N	35.4	27.5	20.5	11.4	10.2	9.4
2009	47	2	6	3	Wheat (CF)	50 N	38.4	27.5	20.0	11.2	9.8	8.0
2009	48	2	6	2	Wheat (CF)	25 N	35.7	27.0	21.6	12.5	8.9	7.9
2009	49	2	6	4	Wheat (CF)	75 N	36.5	29.7	21.6	12.8	10.7	10.6
						100						
2009	50	2	6	5	Wheat (CF)	N	40.3	33.5	23.2	11.1	10.9	9.3
2009	51	2	5	3	Canola (CF)	50 N	34.8	25.9	22.7	12.5	9.0	7.0
						100						
2009	52	2	5	5	Canola (CF)	N	36.3	29.6	23.0	11.8	10.4	8.9
2009	53	2	5	1	Canola (CF)	0 N	36.6	26.7	22.8	10.7	11.2	7.8
2009	54	2	5	2	Canola (CF)	25 N	35.4	27.0	24.4	11.6	10.3	10.8
2009	55	2	5	4	Canola (CF)	75 N	34.9	27.6	22.8	11.4	10.3	7.8
2009	56	2	1	2	Field Pea	25 N	37.0	27.6	23.3	13.5	10.6	11.6
						100						
2009	57	2	1	5	Field Pea	N	43.5	36.6	25.7	13.2	13.0	9.4
2009	58	2	1	4	Field Pea	75 N	34.1	26.7	22.0	12.5	11.4	9.5
2009	59	2	1	1	Field Pea	0 N	36.3	29.7	23.4	12.3	10.5	9.1
2009	60	2	1	3	Field Pea	50 N	36.8	27.5	19.6	13.6	11.2	-7.9
2009	61	3	4	1	Lentil (CF)	0 N	34.9	28.8	23.5	12.9	8.8	10.2
2009	62	3	4	3	Lentil (CF)	50 N	34.7	27.0	23.7	11.5	12.3	11.0
2009	63	3	4	2	Lentil (CF)	25 N	33.9	27.1	16.4	12.3	10.0	7.4
2009	64	3	4	4	Lentil (CF)	75 N	32.1	27.6	17.4	11.0	10.7	9.9
						100						
2009	65	3	4	5	Lentil (CF)	N	34.1	27.8	19.5	12.1	12.3	9.6
2009	66	3	2	4	Fababean	75 N	32.6	21.7	21.3	11.9	8.7	9.9
2009	67	3	2	3	Fababean	50 N	34.7	25.2	23.5	10.8	9.3	9.9
2009	68	3	2	1	Fababean	0 N	32.8	23.0	22.1	12.3	8.6	8.6
						100						
2009	69	3	2	5	Fababean	N	33.1	19.0	17.3	11.5	8.4	9.8
2009	70	3	2	2	Fababean	25 N	35.5	22.1	17.4	9.7	8.1	7.3
2009	71	3	6	3	Wheat (CF)	50 N	36.0	27.3	20.3	10.8	11.0	10.5
						100						
2009	72	3	6	5	Wheat (CF)	N	34.8	26.6	17.0	13.4	10.3	8.0
2009	73	3	6	4	Wheat (CF)	75 N	36.2	30.0	23.3	11.6	12.9	10.4
2009	74	3	6	2	Wheat (CF)	25 N	38.2	30.7	21.6	11.1	11.1	9.9
2009	75	3	6	1	Wheat (CF)	0 N	36.6	27.5	21.2	13.4	10.7	10.8
2009	76	3	3	4	FababeanGM	75 N	38.1	29.8	26.3	13.3	13.0	11.7
						100						
2009	77	3	3	5	FababeanGM	N	35.7	29.7	25.9	13.1	12.4	11.4
2009	78	3	3	1	FababeanGM	0 N	37.4	33.7	25.6	11.4	11.8	9.1
2009	79	3	3	2	FababeanGM	25 N	37.4	28.7	25.0	14.2	12.5	11.6
2009	80	3	3	3	FababeanGM	50 N	36.5	30.5	25.4	12.3	9.5	12.8
2009	81	3	1	1	Field Pea	0 N	35.7	29.2	23.4	11.3	10.5	8.6

YEAR	PLOT	BLOC	MP	SP	Crop	Nrate	0-12" %	12-24" %	24-36" %	0-12" cm	12-24" cm	24-36" cm
2009	82	3	1	3	Field Pea	50 N	37.5	29.9	24.2	13.2	10.8	10.8
2009	83	3	1	2	Field Pea	25 N	36.8	29.6	22.7	12.3	11.7	9.3
						100						
2009	84	3	1	5	Field Pea	N	37.8	30.9	24.7	11.5	11.7	11.5
2009	85	3	1	4	Field Pea	75 N	37.2	29.2	22.1	12.1	11.6	8.0
2009	86	3	5	1	Canola (CF)	0 N	35.6	24.8	22.1	13.1	9.7	11.3
2009	87	3	5	2	Canola (CF)	25 N	34.3	24.0	22.7	12.5	8.3	10.6
2009	88	3	5	4	Canola (CF)	75 N	33.9	23.5	21.5	12.3	9.1	8.7
						100						
2009	89	3	5	5	Canola (CF)	N	29.4	24.9	22.1	10.7	8.9	8.6
2009	90	3	5	3	Canola (CF)	50 N	35.8	25.8	22.2	11.6	9.1	10.1
2009	91	4	4	4	Lentil (CF)	75 N	35.6	26.7	18.6	12.3	10.6	8.8
						100						
2009	92	4	4	5	Lentil (CF)	N	35.5	29.3	23.9	12.9	13.3	11.0
2009	93	4	4	1	Lentil (CF)	0 N	31.2	26.2	20.6	13.3	10.3	9.7
2009	94	4	4	3	Lentil (CF)	50 N	34.6	23.7	20.9	11.6	9.8	8.7
2009	95	4	4	2	Lentil (CF)	25 N	31.5	22.5	19.1	14.6	7.5	11.8
2009	96	4	1	2	Field Pea	25 N	34.3	29.8	19.9	13.1	11.3	9.4
2009	97	4	1	4	Field Pea	75 N	34.1	29.0	24.6	12.3	10.1	11.3
2009	98	4	1	3	Field Pea	50 N	36.5	29.9	26.1	12.6	12.8	12.3
						100						
2009	99	4	1	5	Field Pea	N	33.7	28.8	20.4	11.6	10.8	7.0
2009	100	4	1	1	Field Pea	0 N	36.1	29.2	26.0	11.6	11.4	10.5
2009	101	4	6	2	Wheat (CF)	25 N	35.8	29.9	24.5	12.7	10.8	11.1
2009	102	4	6	3	Wheat (CF)	50 N	35.9	28.6	21.9	13.0	9.7	7.7
						100						
2009	103	4	6	5	Wheat (CF)	N	37.0	33.2	25.0	10.1	11.4	11.8
2009	104	4	6	1	Wheat (CF)	0 N	38.0	29.9	21.9	11.9	13.2	10.2
2009	105	4	6	4	Wheat (CF)	75 N	36.1	32.6	23.9	12.1	11.8	8.4
2009	106	4	3	4	FababeanGM	75 N	39.7	31.3	26.1	13.3	12.6	10.9
						100						
2009	107	4	3	5	FababeanGM	N	34.5	29.6	28.5	12.3	10.6	13.1
2009	108	4	3	2	FababeanGM	25 N	39.8	31.0	26.6	10.0	12.7	9.6
2009	109	4	3	3	FababeanGM	50 N	35.5	29.1	28.3	12.8	11.5	10.5
2009	110	4	3	1	FababeanGM	0 N	34.3	29.4	26.0	12.8	10.8	12.4
						100						
2009	111	4	5	5	Canola (CF)	N	33.2	26.1	16.1	11.5	12.0	7.7
2009	112	4	5	2	Canola (CF)	25 N	34.2	28.5	23.5	11.0	11.3	7.8
2009	113	4	5	1	Canola (CF)	0 N	34.1	27.0	17.6	12.6	11.0	9.3
2009	114	4	5	3	Canola (CF)	50 N	27.4	20.9	35.2	10.2	9.6	12.4
2009	115	4	5	4	Canola (CF)	75 N	33.1	23.4	22.0	11.2	9.4	8.6
						100						
2009	116	4	2	5	Fababean	N	34.8	23.3	22.4	10.1	8.4	6.2
2009	117	4	2	2	Fababean	25 N	32.2	20.8	22.2	11.9	9.2	10.7
2009	118	4	2	4	Fababean	75 N	35.8	22.4	21.0	10.6	7.1	10.7
2009	119	4	2	3	Fababean	50 N	33.6	21.3	20.7	10.8	7.4	8.5
2009	120	4	2	1	Fababean	0 N	31.1	22.3	16.2	11.3	7.1	6.7

Indian Head Research Farm – lab results: Field 300

YEAR	PLOT	CROP S.	ROT	NTMT	ACTUALN	REP	TMT	0- 12" %	12- 24" %	24- 48" %	0- 12"cm	12- 24"cm	24- 48"cm
2009	1	Wheat	1	1	80	1	2	27.4	20.9	22.9	18.7	6.4	18.7
2009	2	Wheat	1	2	80	1	2	33.2	28.4	22.8	19.3	11.1	19.3
2009	3	Wheat	1	3	80	1	2	30.5	23.1	22.5	18.4	8.2	18.4
2009	4	Pea	2	1	0	1	1	30.3	27.0	28.0	25.0	10.8	25.0
2009	5	Pea	2	2	20	1	1	27.7	24.0	28.3	23.9	10.7	23.9
2009	6	Pea	2	3	40	1	1	32.6	25.7	28.8	20.6	10.4	20.6
2009	7	Pea	3	1	0	1	1	30.6	27.5	28.9	23.7	12.0	23.7
2009	8	Wheat	3	3	80	1	2	30.2	22.2	24.4	18.3	8.4	18.3
2009	9	Wheat	3	3	80	1	2	28.9	23.8	23.1	17.7	10.1	17.7
2009	10	Pea	1	1	0	1	1	26.9	25.4	23.9	19.4	10.9	19.4
2009	11	Pea	1	2	20	1	1	28.4	26.2	20.0	13.8	11.5	13.8
2009	12	Pea	1	3	40	1	1	23.2	19.8	17.3	14.0	7.8	14.0
2009	13	Pea	2	3	40	2	1	18.1	10.0	17.2	15.0	4.3	15.0
2009	14	Pea	2	2	20	2	1	22.3	16.5	17.2	14.6	6.3	14.6
2009	15	Pea	2	1	0	2	1	21.0	15.6	16.2	12.7	5.6	12.7
2009	16	Pea	1	2	20	2	1	28.6	24.0	16.6	15.4	10.5	15.4
2009	17	Pea	1	1	0	2	1	28.8	25.9	21.8	19.2	10.6	19.2
2009	18	Pea	1	3	40	2	1	32.4	24.7	20.2	18.4	9.3	18.4
2009	19	Wheat	3	3	80	2	2	29.1	20.2	15.0	12.1	9.0	12.1
2009	20	Wheat	3	3	80	2	2	31.9	25.2	15.3	15.0	9.9	15.0
2009	21	Pea	3	1	0	2	1	29.7	26.7	17.4	17.6	11.3	17.6
2009	22	Wheat	1	2	80	2	2	29.9	21.4	15.6	14.6	7.8	14.6
2009	23	Wheat	1	1	80	2	2	28.0	20.8	14.4	12.5	7.8	12.5
2009	24	Wheat	1	3	80	2	2	32.6	15.3	12.7	10.5	6.3	10.5
2009	25	Pea	1	3	40	3	1	27.0	20.7	15.8	13.0	9.1	13.0
2009	26	Pea	1	1	0	3	1	28.0	22.2	16.8	15.7	9.0	15.7
2009	27	Pea	1	2	20	3	1	28.4	18.6	17.9	15.7	8.2	15.7
2009	28	Wheat	3	3	80	3	2	28.6	20.2	16.3	13.7	9.1	13.7
2009	29	Wheat	3	3	80	3	2	31.9	21.9	15.3	12.5	9.4	12.5
2009	30	Pea	3	1	0	3	1	30.7	23.8	39.8	32.5	10.1	32.5
2009	31	Pea	2	3	40	3	1	27.0	27.6	18.4	18.3	11.6	18.3
2009	32	Pea	2	2	20	3	1	28.0	22.8	18.0	17.4	7.5	17.4
2009	33	Pea	2	1	0	3	1	29.3	27.8	21.5	19.6	11.3	19.6
2009	34	Wheat	1	3	80	3	2	28.3	21.9	17.4	17.5	7.1	17.5
2009	35	Wheat	1	1	80	3	2	27.3	22.4	18.3	16.1	6.8	16.1
2009	36	S.	1	2	80	3	2	27.3	22.5	19.7	17.2	9.5	17.2

		Wheat											
2009	37	Pea	3	1	0	4	1	31.1	22.4	20.4	18.1	9.3	18.1
		S.											
2009	38	Wheat	3	3	80	4	2	31.1	21.4	21.9	17.9	9.2	17.9
		S.											
2009	39	Wheat	3	3	80	4	2	30.6	22.0	22.0	17.2	8.4	17.2
		S.											
2009	40	Wheat	1	3	80	4	2	31.0	25.1	19.0	15.0	8.4	15.0
		S.											
2009	41	Wheat	1	2	80	4	2	26.1	19.6	17.6	13.8	7.8	13.8
		S.											
2009	42	Wheat	1	1	80	4	2	27.6	21.1	18.5	16.7	7.1	16.7
2009	43	Pea	1	3	40	4	1	30.0	19.9	18.0	17.0	7.8	17.0
2009	44	Pea	1	2	20	4	1	28.1	12.6	13.6	12.6	5.8	12.6
2009	45	Pea	1	1	0	4	1	23.1	12.6	16.1	13.8	5.4	13.8
2009	46	Pea	2	1	0	4	1	20.6	17.5	19.4	19.0	6.3	19.0
2009	47	Pea	2	3	40	4	1	24.2	12.8	22.4	20.2	5.7	20.2
2009	48	Pea	2	2	20	4	1	25.0	21.9	25.1	21.1	9.2	21.1

Indian Head Research Farm, Field 300 - Electromagnetic Readings, Sept. 29, 2009

		Ground				Height = 0.6 m				Sept 28,2009	
		Vertical	Horizontal	V	H	Vertical	Horizontal	V	H		
1		62	45	60	40	36	10	35	7		
2		64	55			36	12				
3		61	43			34	9				
4		78	58	76	57	42	15	41.5	13		
5		83	65			44	16				
6		82	63.5			45	16.5				
7		87	76	86	72.5	46	19	45	16.5		
8		69	55			39	12.5				
9		68	56			38	12.5				
10		74	53	73	54.4	40	13.5	38.5	11.5		
11		71	55			39	13				
12		64	43			34	10				
13		43	28.5	41	29.5	26	4	24.5	2		
14		45	30			25	3.5				
15		44.5	29			26	3				
16		60	44	58.5	41.5	33	8	31.5	6.5		
17		67	52			36	10.5				
18		72	60			39	12.5				
19		65	53.5	64	51	38	10.5	36.9	9		
20		68	61			39	13				
21		75	67			41	14				
22		64	55	62	50.5	36.5	10.5	35.5	9		
23		60	47			35	9.5				
24		60	45			34.5	8.5				
25		70	55	69.5	57.5	38	10.5				
26		66	49			36	10				
27		62	48.5			33	8				
28		60	45.5			33	8				
29		63	51			35	9.5				
30		74	62			39	12				
31		71	64			37	11				
32		70	61			38	11				
33		76	58.5			39	12				
34		58	46			34	8.5				
35		58	46			31.5	7				
36		56	41.5			32	6			est. location	
37		60	50.5			33	8.5				
38		53	37.5			30	6				
39		54	39			31.5	6				
40		54	38			30	5.5			est. location	
41		52	34.5			30	5.5				
42		55	44.5			32	7				
43		63	51.5			35	9.5				
44		52.5	37			30	6.5				

45	51	30			29	5.5		
46	51	31			30	5.5		
47	59	37			32	7		
48	64	45			35	9		

Indian Head Research Farm, Field 1436 - Electromagnetic Readings - October 24, 2009

Rep1				Rep2				Rep3				Rep4		
OLD		NEW		OLD		NEW		OLD		NEW		OLD		NE
V	H	V	H	V	H	V	H	V	H	V	H	V	H	V
		58	56.5	68	64	69	68	68	67	65	71	61	61	62
60	62	59	60	70	72	71	72	69	68	70	66	66	64	65
63	62	62	58	69	70	67	71	64	64	67	63	66	69	65
69	65	68	63	69	73.5	69	71	63	63	62	63.5	66	65	65
71	66	70	63	71	73	71	73	68	71	69	69	69	65.5	67
85	79	85	78	61	59	60	62	63	64	61	60.5	73	66	71
		83	77	56	58	55	53.5	57	56.5	57	52	71	68	72
79	79	71	71	56	56	57	57	54	55	55	54	73	68	73
77.5	73.5	80	75	59.5	63	61	62	55	51	53	54	69	69	69
80	76.5	81	73	62	59	61	58	52	50	52	48	68	67	68
78	73	78	73	76	71	75	69	64	59	57	55	67	63	67
77	72	76.5	74	79	69.5	80	71	66	63	65	63	68	65	66
74	73	78	74			78	74	67	64	68	61	69	65	69
74	70	75	73	79	72	81	73	66	59	67	65	68	62	69
75	73.5	76	71	80	69	81	70	71	66.5	69	65	70	64	71
75	68	74	70	68	65	70	64	82	71	81	72	81	72.5	80
74	70	70	71	65	60	69	66.5			85	72	79	75	80
69	66	69	66	63	61	64	65			80	75	77	68	77
68	66	68	64	66	68.5	64	58			80	78			76
69	66	70	63	68	67	68	64			79	72	69	66.5	71
64	58	63	59	66	62.5	66	63	73	69	73	65	58.5	59	58
62	62	63	60.5	67	63	67	65	72	66	72	64	63.5	62.5	60
63	61	63	64	65	62	65	66	71	65	70	64	61	61	59
60		65.5	61.5	65	63	65	64	69	64	72	65	62	65	59
67.5	63	66	63	67	64	67	64	69	66	70	63	64	57	61
73	69	68	61	74	70	72	69	66	63	63	58	61	51.5	59.5
67	69	65.5	61.5	71	65	68	68	61	56.5	60	57	58	53.5	59
65	65	63	57	69	65	68	68	63	59	61	59	59	50	58
59	59	62	59	68	62	69	68	63	57	60	59	57	51	55
64	63	70	68	71	67	69.5	66	63	59	62	60	63	54	62

Estimated readings are in yellow. Unstable readings are in red.

APPENDIX 3C **Conductivity readings and soil core lab results** **Sask. Irrigation Branch, 2009 Field Season**

Project:		Land Location:	EM38 Readings:					
Riverhurst		NE 12-23-07-W3M	Hole #5		Hole #6		Hole #7	
			H	V	H	V	H	V
		Ground	39	62	19	24	11	15
		25 cm	28	48	13	19	7	12
		50 cm	20	38	7	15	4	10
		75 cm	16	31	7	11	2	7
		100 cm	12	24	3	8	2	4
		125 cm	10	21	3	6	1	4
		150 cm	8	17	2	5	0	3

Riverhurst	NW 7-23-06-W3M									
		Hole #1		Hole #2		Hole #3		Hole #4		
		H	V	H	V	H	V	H	V	
		Ground	50	77	17	25	123	137	200	241
		25 cm	35	60	10	18	76	111	124	187
		50 cm	24	46	6	13	46	80	80	136
		75 cm	18	37	4	10	31	58	56	101
		100 cm	14	27	3	7	23	43	41	78
		125 cm	11	23	2	6	17	34	32	62
		150 cm	9	19	2	6	13	27	26	50

Grainland	NW 4-23-04-W3M	Hole #1		Hole #2		Hole #3		Hole #4		
		H	V	H	V	H	V	H	V	
		Ground	21	30	5	13	5	13	10	57
		25 cm	11	22	1	10	7	2	15	42
		50 cm	4	16	5	8	8	2	8	33
		75 cm	0	11	5	7	8	1	8	24
		100 cm	-4	8	5	5	8	1	7	21
		125 cm	-5	6	5	3	8	0	7	16
		150 cm	-6	4	5	2	8	-1	7	13

Aberdeen		Pt NW 14 & SW 23-37-04-W3M		Hole #1		Hole #2		Hole #3		Hole #4		Hole #5			
				H		V		H		V		H		V	
				H	V	H	V	H	V	H	V	H	V		
		Ground	30	43	22	34	41	68	12	14	55	75			
		25 cm	21	35	14	24	29	50	9	12	36	60			
		50 cm	14	26	9	18	19	38	5	9	23	46			
		75 cm	10	21	6	14	13	29	3	6	16	37			
		100 cm	6	15	4	11	7	21	1	4	12	30			
		125 cm	4	12	0	10	4	16	-1	1	9	25			
		150 cm	1	8	-1	6	-3	9	3	0	8	22			

Riverhurst	NW 24-23-07-W3M	Hole #1		Hole #2		Hole #3	
		H	V	H	V	H	V
	Ground	5	7	13	15	18	25
	25 cm	3	5	7	11	10	18
	50 cm	0	3	2	7	5	12
	75 cm	0	2	-1	4	2	7
	100 cm	1	2	-2	1	0	5
	125 cm	1	2	-3	1	0	2
	150 cm	1	2	0	0	-2	1

Maple Creek	S1/2 24-10- 26-W3M	Hole #1		Hole #2		Hole #3		Hole #4	
		H	V	H	V	H	V	H	V
	Ground	10	14	17	21	39	53	24	43
	25 cm	7	11	12	17	28	43	13	33
	50 cm	5	9	7	14	20	33	14	24
	75 cm	2	8	4	11	14	28	-3	20
	100 cm	1	7	1	9	10	22	-5	12
	125 cm	1	5	3	7	10	18	-5	11
	150 cm	1	4	2	5	6	15	-7	8

Soil Analytical Results														
EM 38 Reading	Field Sample #	Depth (cm)	Texture	Cl- (mg/l)	Ca++ (mg/l)	Mg++ (mg/l)	K+ (mg/l)	Na+ (mg/l)	SO ₄ = (mg/l)	S.A.R.	% SAT	E.C. (mS/cm)	pH	
NW7-23-05-W3M	Hole #1 V 69 H 45 Moderate Salinity Moderate Sodicity	JT-01	0 - 30	L	186	116	46.3	22.8	51.8	51.3	1.03	45.0	1.17	6.80
		JT-02	30 - 60	L(Hv)	62.0	41.4	28.9	3.7	31.5	62.7	0.92	40.0	0.56	7.23
		JT-03	60 - 90	CL	102	451	679	10	835	5260	5.81	52.0	7.09	7.92
		JT-04	90 - 120	SiCL	144	215	880	<20	1470	6680	9.94	60.0	9.13	8.31
	Hole #2 V 20 H 12 No Salinity No Sodicity	JT-05	0 - 30	CL	11.6	149	52.6	33.2	47.0	397	0.84	45.0	1.24	6.93
		JT-06	30 - 60	L(Hv)	6.1	72.6	25.7	12.6	12.3	79.4	0.32	41.0	0.57	7.26
		JT-07	60 - 90	FSL	3.1	97.0	43.6	11.6	17.0	339	0.36	37.0	0.88	7.59
		JT-08	90 - 120	FSL	<3.0	29.4	24.5	9.8	9.0	88.3	0.30	38.0	0.42	7.94
	Hole #3 V 121 H 130 Severe Salinity, Moderate Sodicity	JT-09	0 - 30	CL	61.6	453	627	350	1650	7100	11.8	82.0	10.8	7.79
		JT-10	30 - 60	CL	47.4	457	549	272	1430	6260	10.7	52.0	9.49	8.05
		JT-11	60 - 90	CL	37.6	430	395	187	1010	4860	8.49	45.0	7.63	8.05
		JT-12	90 - 120	CL	41.2	461	359	149	963	4570	8.17	46.0	7.19	8.03
	Hole #4 V 214 H 188 Severe Salinity, Severe Sodicity	JT-13	0 - 30	SCL	71.6	434	776	246	2530	9280	16.9	73.0	13.7	8.01
		JT-14	30 - 60	SCL	77.4	441	948	257	3460	12200	21.3	49.0	17.0	8.34
		JT-15	60 - 90	SL	93.4	445	1230	234	3950	13900	21.9	44.0	19.5	8.30
		JT-16	90 - 120	SCL	66.2	332	877	186	3060	10700	20.0	52.0	15.6	8.32

		EM 38 Reading	Field Sample #	Depth (cm)	Texture	Cl- (mg/l)	Ca++ (mg/l)	Mg++ (mg/l)	K+ (mg/l)	Na+ (mg/l)	SO ₄ = (mg/l)	S.A.R.	% SAT	E.C. (mS/cm)	pH
NE12-23-07-W3M	Hole #5	V 39 H 34 No Salinity No Sodcity	LM-49	0 - 30	L	13.0	51.4	16.9	22.7	11.7	48.1	0.36	44.0	0.49	7.10
			LM-50	30 - 60	FSL	27.6	60.6	18.2	12.0	13.2	38.4	0.38	40.0	0.52	7.59
			LM-51	60 - 90	FSL	9.3	47.2	27.6	13.0	18.4	90.8	0.53	36.0	0.53	8.00
			LM-52	90 - 120	SIL	19.2	65.4	151	20.2	286	1190	4.45	47.0	2.49	8.23
	Hole #6	V 7 H 16 No Salinity No Sodcity	LM-53	0 - 30	SIL	25.6	105	41.8	47.5	25.3	106	0.53	47.0	1.01	6.94
			LM-54	30 - 60	CL	16.7	54.1	20.0	9.8	12.7	26.9	0.38	46.0	0.50	7.14
			LM-55	60 - 90	CL	13.9	35.3	21.7	7.7	14.4	48.1	0.47	44.0	0.42	7.74
			LM-56	90 - 120	SICL	160	120	218	19.0	186	1280	2.34	51.0	3.06	7.98
	Hole #7	V 1 H 14 No Salinity No Sodcity	LM-57	0 - 30	L	8.8	84.3	32.7	14.1	10.8	54.2	0.25	45.0	0.71	7.03
			LM-58	30 - 60	L	4.6	49.4	21.1	6.4	9.1	32.2	0.27	45.0	0.41	7.87
			LM-59	60 - 90	FSL	<3.0	29.3	44.0	7.4	14.0	107	0.38	40.0	0.53	8.27
			LM-60	90 - 120	FSL	3.6	13.2	45.5	9.6	20.5	100	0.60	35.0	0.51	8.48

		EM 38 Reading	Field Sample #	Depth (cm)	Texture	Cl- (mg/l)	Ca++ (mg/l)	Mg++ (mg/l)	K+ (mg/l)	Na+ (mg/l)	SO ₄ = (mg/l)	S.A.R.	% SAT	E.C. (mS/cm)	pH
NW24-23-07-W3M	Hole #1	V-0.4 H 0.3 No Salinity, No Sodicity	FH-01	0 - 30	L	7.1	94.3	28.4	7.8	23.5	155	0.55	46.0	0.79	7.26
			FH-02	30 - 60	SCL	9.5	49.6	21.4	4.1	7.1	52.4	0.21	34.0	0.46	7.83
			FH-03	60 - 90	SL	11.0	40.1	26.3	4.7	9.6	25.1	0.29	26.0	0.41	8.06
			FH-04	90 - 120	LS	4.1	30.7	23.3	5.1	9.0	25.8	0.30	23.0	0.37	8.13
	Hole #2	V 5 H 10 No Salinity No Sodicity	FH-05	0 - 30	CL	4.1	60.7	23.8	9.6	5.5	18.0	0.15	47.0	0.53	7.20
			FH-06	30 - 60	SIL	3.7	33.5	24.4	4.9	9.1	31.4	0.29	48.0	0.40	7.89
			FH-07	60 - 90	SICL	4.3	16.6	37.7	6.2	15.9	42.4	0.49	58.0	0.46	8.29
			FH-08	90 - 120	SIL	3.9	12.2	38.1	7.5	25.7	47.0	0.82	39.0	0.48	8.45
	Hole #3	V 8 H 15 No Salinity No Sodicity	FH-09	0 - 30	CL	3.5	69.9	21.8	43.3	5.7	24.5	0.15	46.0	0.70	6.68
			FH-10	30 - 60	SC	5.2	30.5	9.4	24.4	7.8	24.7	0.31	46.0	0.36	6.54
			FH-11	60 - 90	SIC	4.0	26.2	8.2	18.1	6.7	24.8	0.29	52.0	0.29	6.56
			FH-12	90 - 120	SCL	7.5	23.4	7.9	16.1	7.0	16.4	0.32	60.0	0.27	6.85

		EM 38 Reading	Field Sample #	Depth (cm)	Texture	Cl- (mg/l)	Ca++ (mg/l)	Mg++ (mg/l)	K+ (mg/l)	Na+ (mg/l)	SO ₄ = (mg/l)	S.A.R.	% SAT	E.C. (mS/cm)	pH
NW4-23-04-W3M	Hole #1	V 36 H 24 Moderate Salinity No Sodicty	MO-01	0 - 30	L	8.6	74.9	22.2	33.2	10.5	32.8	0.27	47.0	0.64	7.15
			MO-02	30 - 60	L	263	513	667	18	351	4080	2.41	47.0	6.40	7.91
			MO-03	60 - 90	SIL	184	386	1200	24	720	6900	4.07	52.0	9.32	8.24
			MO-04	90 - 120	SIL	159	165	1000	29	735	5630	4.75	52.0	8.20	8.25
	Hole #2	V 22 H 10 No Salinity No Sodicty	MO-05	0 - 30	FL	4.5	59.0	11.9	14.7	6.2	61.5	0.19	37.0	0.46	7.63
			MO-06	30 - 60	FL	4.3	45.8	8.6	22.9	5.8	18.6	0.21	35.0	0.36	7.83
			MO-07	60 - 90	FL	6.3	31.5	9.0	28.6	5.1	14.0	0.21	35.0	0.32	8.00
			MO-08	90 - 120	FL	6.0	28.8	16.1	7.9	7.9	11.9	0.29	33.0	0.32	8.14
	Hole #3	V 15 H 2 No Salinity No Sodicty	MO-09	0 - 30	L	5.9	49.6	12.9	3.0	5.4	13.6	0.18	42.0	0.37	7.59
			MO-10	30 - 60	SIL(gr)	9.7	69.1	26.1	5.5	12.8	55.8	0.33	34.0	0.63	7.82
			MO-11	60 - 90	gr	13.8	40.5	22.1	5.7	14.5	46.7	0.46	23.0	0.48	8.05
			MO-12	90 - 120	SIL(gr)	9.5	70.2	19.1	5.0	8.0	27.5	0.22	37.0	0.51	7.71
	Hole #4	V 61 H 37 Moderate Salinity, Slight Sodicty	MO-13	0 - 30	L	28.9	177	45.0	19.4	50.8	455	0.88	45.0	1.37	7.41
			MO-14	30 - 60	L	22.1	485	457	16	627	4180	4.91	39.0	6.19	7.97
			MO-15	60 - 90	SIL	4.0	469	588	33	795	5110	5.78	49.0	7.33	8.08
			MO-16	90 - 120	SIL	<3.0	425	584	37	887	5210	6.56	61.0	7.67	8.02

		EM 38 Reading	Field Sample #	Depth (cm)	Texture	Cl- (mg/l)	Ca++ (mg/l)	Mg++ (mg/l)	K+ (mg/l)	Na+ (mg/l)	SO ₄ = (mg/l)	S.A.R.	% SAT	E.C. (mS/cm)	pH
Pt NW 14 & SW 23-37-04-W3M	Hole #1	V 30 H 23 No Salinity No Sodicity	BC-01	0 - 30	L	12.3	39.3	18.4	9.6	7.9	112	0.26	49.0	0.40	5.94
			BC-02	30 - 60	CL	9.5	54.4	35.7	4.5	9.8	78.9	0.25	47.0	0.56	7.45
			BC-03	60 - 90	SICL	4.7	14.2	29.3	4.0	32.3	24.1	1.12	57.0	0.39	8.35
			BC-04	90 - 120	SICL	12.9	15.4	48.6	5.3	127	254	3.58	60.0	0.92	8.57
	Hole #2	V 18 H 14 No Salinity No Sodicity	BC-05	0 - 30	L	4.9	60.1	19.9	24.2	6.9	23.5	0.20	46.0	0.52	6.63
			BC-06	30 - 60	FSL	4.3	50.3	17.6	5.1	7.0	18.3	0.22	43.0	0.41	7.50
			BC-07	60 - 90	VSL	4.7	35.4	18.2	5.1	8.2	25.9	0.28	42.0	0.33	8.05
			BC-08	90 - 120	SICL	5.5	34.4	32.2	8.9	13.1	50.3	0.39	35.0	0.49	8.09
	Hole #3	V 46 H 36 Slight Salinity No Sodicity	BC-09	0 - 30	SIC	13.4	101	40.8	26.7	9.2	30.4	0.20	54.0	0.82	6.76
			BC-10	30 - 60	SIC	18.0	38.8	27.5	5.4	17.2	59.0	0.52	58.0	0.49	8.03
			BC-11	60 - 90	SICL	12.2	44.8	125	8.3	149	777	2.58	66.0	1.71	8.31
			BC-12	90 - 120	SIC	74.9	487	737	20	406	4710	2.71	59.0	6.36	8.01
	Hole #4	V 0 H 6 No Salinity No Sodicity	BC-13	0 - 30	SIC	6.6	202	82.0	14.2	16.1	665	0.24	53.0	1.37	7.70
			BC-14	30 - 60	TIH	7.2	29.3	40.2	3.6	11.7	70.4	0.33	44.0	0.52	8.23
			BC-15	60 - 90	SICL	11.6	15.2	62.9	5.8	52.0	198	1.31	37.0	0.79	8.51
			BC-16	90 - 120	SIL(Gr)	18.9	19.4	101	4.2	186	640	3.76	40.0	1.61	8.56

	Hole #5	V 55 H 44 Slight Salinity No Sodicity	BC-17	0 - 30	L	37.4	104	43.2	22.7	30.6	157	0.64	50.0	0.95	6.92
			BC-18	30 - 60	SIC	425	192	137	13.3	56.5	408	0.76	51.0	2.31	7.30
			BC-19	60 - 90	SIC	141	215	313	21	179	1820	1.82	69.0	3.46	7.92
			BC-20	90 - 120	SIC	86.1	233	519	28	321	3020	2.68	70.0	4.83	8.06

S1/2 24-10-26-W3M															
		EM 38 Reading	Field Sample #	Depth (cm)	Texture	Cl- (mg/l)	Ca++ (mg/l)	Mg++ (mg/l)	K+ (mg/l)	Na+ (mg/l)	SO ₄ = (mg/l)	S.A.R.	% SAT	E.C. (mS/cm)	pH
	Hole #1	V 7 H 8 No Salinity No Sodicity	RM-01	0 - 30	FSL	8.1	235	65.8	40.5	35.6	625	0.53	50.0	1.55	6.79
			RM-02	30 - 60	FSL(gr)	6.6	132	41.2	12.7	15.7	341	0.31	45.0	0.93	7.41
			RM-03	60 - 90	FSL(gr)	31.3	135	89.0	25.6	78.2	639	1.28	45.0	1.49	7.63
			RM-04	90 - 120	FSL(gr)	41.1	91.4	52.1	23.0	58.4	269	1.21	45.0	1.04	7.60
	Hole #2	V 15 H 14 No Salinity No Sodicity	RM-05	0 - 30	SL	5.9	62.8	25.1	11.5	10.2	83.5	0.28	49.0	0.53	6.60
			RM-06	30 - 60	SIL	8.1	66.0	34.5	7.5	17.9	105	0.45	59.0	0.61	7.60
			RM-07	60 - 90	CL	3.8	36.0	34.3	6.1	43.3	137	1.24	44.0	0.60	8.00
			RM-08	90 - 120	CL	7.0	38.6	34.5	7.2	50.7	148	1.43	43.0	0.65	8.03
	Hole #3	V 44 H 34 Moderate Salinity Moderate Sodicity	RM-09	0 - 30	L	9.3	73.7	38.5	15.9	16.9	73.2	0.40	44.0	0.69	6.72
			RM-10	30 - 60	SL	28.1	23.1	17.1	4.4	89.7	112	3.45	45.0	0.62	6.95
			RM-11	60 - 90	SL	122	554	1720	<40	1930	11800	9.14	40.0	14.2	8.26
			RM-12	90 - 120	SL	106	588	1640	<40	2390	12700	11.5	43.0	15.3	8.27
	Hole #4	V 33 H 34 Moderate Salinity Slight Sodicity	RM-13	0 - 30	FSL	7.2	133	62.3	24.7	25.1	392	0.45	45.0	1.13	7.13
			RM-14	30 - 60	SCL	23.2	24.6	26.3	7.2	101	140	3.38	43.0	0.72	7.56
			RM-15	60 - 90	CL	193	516	1720	46	1630	11000	7.75	49.0	13.2	8.24
			RM-16	90 - 120	VL	235	504	1570	43	1610	10400	8.00	51.0	12.8	8.35

APPENDIX 4

Testing model predictions against soil core lab results

Comparing Ratios to Outlook Data

This worksheet uses the functions developed from the Maple sheet "EM38 2-layer ratios" to see how well they predict the Outlook core data.

For this first set, we specifically chose holes that are reasonably close to two-layer earths, using the lab results to generate the modeled ratio (Vertical to Horizontal)

	NE12-23-07- W3M Riverhurst Hole 5		NW24-23-07- W3M Riverhurst Hole 1		NW24-23-07- W3M Riverhurst Hole 3		NW24-23-07- W3M Riverhurst Hole 2		NW24-23-07- W3M Riverhurst Hole 2		S1/2 24-10-26- W3M Maple Creek Hole 2		S1/2 24-10-26- W3M Maple Creek Hole 3	
	Well-defined two-layer earth		Poorly defined two-layer earth		Poorly defined two-layer earth		Modeled as homogenous		Modeled as two- layer		Extreme two- layer case		Extreme two- layer case	
Height (m)	Observed	Model ed	Observed	Model ed	Observed	Model ed	Observed	Model ed	Observed	Model ed	Observed	Model ed	Observed	Model ed
0.00	1.59	1.44	1.40	0.81	1.39	0.76	2.60	1.00	2.60	0.95	1.24	1.05	1.36	1.68
0.25	1.71	1.71	1.67	1.33	1.80	1.29	10.00	1.45	10.00	1.41	1.42	1.48	1.54	1.82
0.50	1.90	1.85	#DIV/0!	1.64	2.40	1.62	1.60	1.71	1.60	1.69	2.00	1.72	1.65	1.89
0.75	1.94	1.91	#DIV/0!	1.79	3.50	1.78	1.40	1.83	1.40	1.82	2.75	1.84	2.00	1.93
1.00	2.00	1.94	2.00	1.87	#DIV/0!	1.86	1.00	1.89	1.00	1.89	9.00	1.90	2.20	1.95
1.25	2.10	1.96	2.00	1.91	#DIV/0!	1.91	0.60	1.93	0.60	1.92	2.33	1.93	1.80	1.96
1.50	2.13	1.97	2.00	1.94	-0.50	1.94	0.40	1.95	0.40	1.95	2.50	1.95	2.50	1.97

Model Vars:

T	0.9	0.3	0.3	0.6	0.3	0.6
sigma 1	51	79	70	36	40	53
sigma 2	250	42	31	33	62	1460

	NE12-23-07- W3M Riverhurst Hole 5	NW24-23-07- W3M Riverhurst Hole 1	NW24-23-07- W3M Riverhurst Hole 3	NW24-23-07- W3M Riverhurst Hole 2	NW24-23-07- W3M Riverhurst Hole 2	S1/2 24-10-26- W3M Maple Creek Hole 2	S1/2 24-10-26- W3M Maple Creek Hole 3
	Well-defined two-layer earth	Poorly defined two-layer earth	Poorly defined two-layer earth	Modeled as homogenous	Modeled as two- layer	Extreme two- layer case	Extreme two- layer case
Comments:	In this well defined case, the two layer approximation worked well in the region of high validity (unshaded).	The H reading went to 0 too quickly to provide a useful comparison.	Although the trend matched, again the H reading approached 0 too rapidly. Even by 0.5m height, we are dealing with relative error clearly well over tolerable levels.	This hole was nearly homogenous with only a slight negative conductivity trend with depth. Neither model represented the actual case with much success, again due in part to the overall low apparent conductivity readings (high relative error).		The trend follows correctly and values are reasonably well defined for the subtle change, but still break down rapidly beyond 50cm height.	The model predicts a less extreme change with height than is observed. This is because the top 30cm is more conductive than the second 30cm. Aside from that, we see good coherence.